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FUZZY METHODS AND TOOLS FOR CRANE MANAGEMENT SYSTEM BASED ON T-CONTROLLER

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Abstract: The problem and the comparative analysis of the possible control gantry cranes methods are represented. T-Controller fuzzy interference system is selected for further work. Mathematical equations of motion are calculated using the equations of Lagrange and methods of Euler and Runge-Kutta.

Keywords: gantry crane, fuzzy interference system (FIS), fuzzy logic, T-Controller application, crane management system.

INTRODUCTION

Industrial cranes are widely used in modern logistics for transportation of load within a given trajectory. For instance, the gantry crane moves load from point to point in horizontal direction. Usually a skilful operator manages this task.

During this process, the load might swing in a pendulum-like motion. If the swing exceeds a proper limit, it must be reduced or the operation must be interrupted until the swing stops.

One of the ways to improve control efficiency of such kind of process is based on the using of human experience and the fuzzy modeling [1].

Fuzzy modeling uses fuzzy logic controller what allows to solve adverse effects problems, caused by system nonlinearities.

TASK

The main goal is to develop a reliable, fast and usable control system for gantry cranes. System should manage quick transfer of load from point to point with the ability to control swinging of this load. As the result the crane cart with goods has not cross out the permissible swinging limits.

The swing manage is realized by controlling of the three main parameters: the angle relative to the vertical axis of the cart, cart position relative to the start/end point and the power in corresponding point.

Fuzzy Interference System:

At present distinct mathematical model for cranes managing is not designed because of problem's formulation ambiguity. Therefore, controller based on fuzzy productive system's conception is chosen.

Fuzzy Inference System (FIS) - fuzzy logic makes use of human common sense or expert knowledge to build control systems or model data. A fuzzy inference system applies fuzzy if-then rules that can model the qualitative aspects of human knowledge and reasoning processes without using precise quantitative analyses.

However, common fuzzy inference systems have several issues. For example, good interpretability vs. good accuracy, small number of input variables, time consuming tuning, requires sufficient data basis and dependency on defuzzification method: same rules give different results depending on defuzzification.

All of these issues limit the usage of the existing fuzzy systems for managing complex technical objects.

Fuzzy inference system algorithms:

Mamdani and Takagi-Sugeno algorithms are the most popular and well known among FIS algorithms and also might be employed in the crane cart control system.

On the one hand Mamdani algorithm has the plus, like flexibility in the rules design and fuzzy logic method implementation, based on experiments and extension expert’s knowledge represent management system as the transparent and understandable to the user. On the other hand this algorithm also has following minuses: multivariant defuzzification procedure, each of the existing defuzzification methods provide different low accuracy results and as a result, more time is required to properly configure the system. Overall, the low rate of result formation within allowable time delay.

In comparison to Mamdani, Takagi-Sugeno algorithm applicable only in case sufficient numerical data, which obtained through field experiments, are available. Nonetheless, if the model parameters vary depending on the configuration, the nature or load size, use of such fuzzy inference system, in generally, inappropriate, as it requires the creation of separated models for each divided area for the formation of appropriate control actions, which significantly affects the system performance.

T-Controller fuzzy system of improved accuracy:

T-Controller FIS is an original method of fuzzy logic. In contrast to traditional fuzzy inference systems, T-Controller is based on peculiar defuzzification method and rule building is driven by expected output, rules are disjunctive: each output value corresponds only to one rule. Also expert assessments interval can be used for rules constructing in T-Controller [2].

Accordingly T-Controlled has several main advantages over common fuzzy systems, such as:

The logic inference (and) and the composition (or) are combined into one specific step;

The number of rules conditioned by features only output variables;
Fast defuzzification;

The rules designing procedure is intuitively understood for experts via analysis of possible situations for output variable;
High accuracy of T-Controller – high speed geometrical defuzzification method with zero systematic error (more strict «input» gives more precise «output»);
The procedure of configuration is faster;

Simplicity in implementation in both software and hardware versions. On the figure below T-Controller application is demonstrated [2, 3].

The simplified model of the gantry crane

The equation of the crane motion

The simplified model of the gantry crane is shown on the Fig.2, where: x_c is a position of the cart relative to the starting point, x_p and y_p are positions of the center of mass, M_c is the weight of the cart, M_p is the weight of the crane, α is an angle of the cart, F_c is an external force applied to the cart [4].
This single pendulum can be represented as a system with one input parameter *u* (the power of crane) and two output: *a* (angle of the cart) and x_c (cart position) [5].

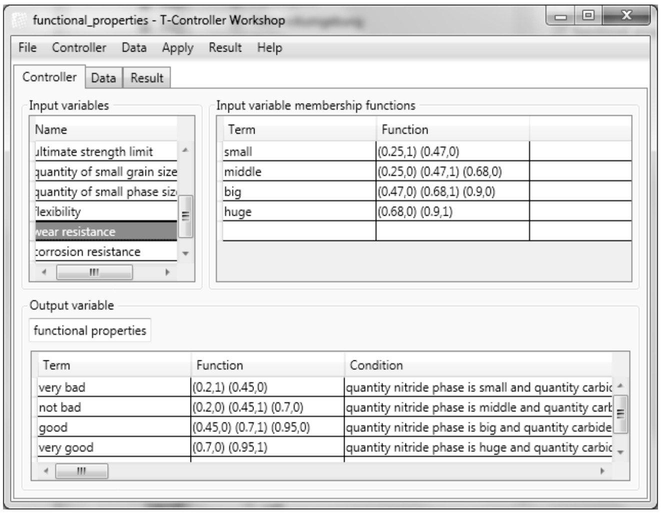


Figure: 1

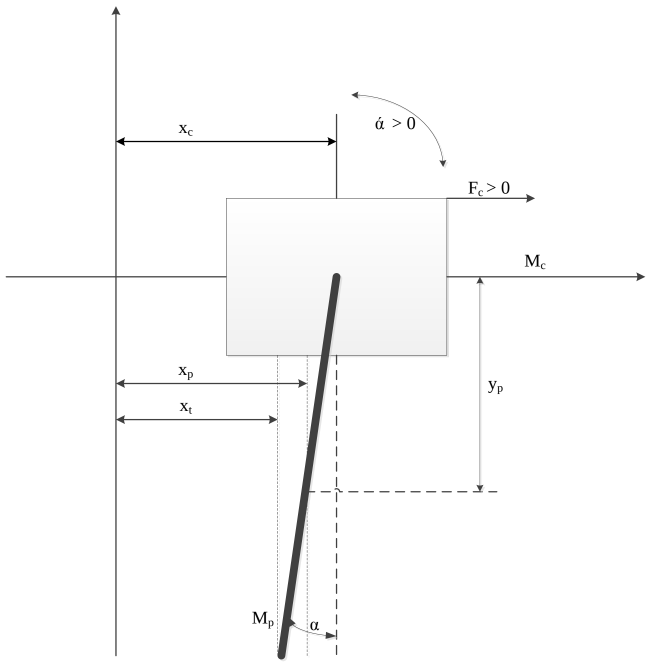


Figure: 2 The simplified model of the gantry crane

The mathematical equations of motion (1) and (2) can be calculated by using Lagrange equations with the total potential and the kinetic energy.

After the linearization of nonlinear single model of the gantry crane is received the following system of differential equations that represented in (3) and (4).

$$\ddot{x}_c = \frac{-(I_p + M_p l_p^2) B_{eq} \cdot \dot{x}_c + (M_p^2 l_p^3 + l_p M_p I_p) \sin(\alpha)\, \dot{\alpha}^2 + M_p l_p \cos(\alpha)\, B_p \dot{\alpha}}{(M_c + M_p) I_p + M_c M_p l_p^2 + M_p^2 l_p^2 sin^2(\alpha(t))} \tag{1}$$

$$+ \frac{M_p^2 l_p^2 g \cos(\alpha) \sin(\alpha) - (I_p + M_p l_p^2) \frac{\eta_g K_g^2 \eta_m K_t K_m \cdot \dot{x}_c}{R_m r_{mp}^2} + (I_p + M_p l_p^2) \frac{\eta_g K_g \eta_m K_t}{R_m r_{mp}} U_m)}{(M_c + M_p) I_p + M_c M_p l_p^2 + M_p^2 l_p^2 sin^2(\alpha)}$$

$$\ddot{\alpha} = \frac{-(M_c + M_p) B_p \cdot \dot{\alpha} - M_p^2 l_p^2 \sin(\alpha) \cos(\alpha) \cdot \dot{\alpha}^2 + M_p l_p \cos(\alpha) B_{eq} \cdot \dot{x}_c}{(M_c + M_p) I_p + M_c M_p l_p^2 + M_p^2 l_p^2 sin^2(\alpha)} \tag{2}$$

$$+\frac{-(M_c+M_p)M_p g\, l_p \sin(\alpha)+(M_p l_p \cos(\alpha)\frac{\eta_g K_g^2 \eta_m K_t K_m \cdot \dot{x}_c}{R_m r_{mp}^2}-M_p l_p \cos(\alpha)\frac{\eta_g K_g \eta_m K_t}{R_m r_{mp}}U_m)}{(M_c+M_p)I_p+M_c M_p l_p^2+M_p^2 l_p^2 sin^2(\alpha)}$$

$$\begin{bmatrix}\dot{x}_c(t)\\ \dot{\alpha}(t)\\ \ddot{x}_c(t)\\ \ddot{\alpha}(t)\end{bmatrix}=\begin{bmatrix}0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ 0 & 1.5216 & -11.6513 & 0.0049\\ 0 & -26.1093 & 26.8458 & -0.0841\end{bmatrix}\cdot\begin{bmatrix}x_c(t)\\ \alpha(t)\\ \dot{x}_c(t)\\ \dot{\alpha}(t)\end{bmatrix}+\begin{bmatrix}0\\ 0\\ 1.5304\\ -3.5261\end{bmatrix}\cdot U_m(t) \quad (3)$$

$$\begin{bmatrix}x_c\\ \alpha(t)\end{bmatrix}=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\end{bmatrix}\cdot\begin{bmatrix}x_c(t)\\ \alpha(t)\\ \dot{x}_c(t)\\ \dot{\alpha}(t)\end{bmatrix} \quad (4)$$

Table I. Parameters from equantiions (1) and (2)

Parameters	Description
B_{eq}=5.4 [Nms/rad]	equivalent viscous damping coefficient as seen at the motor pinion
B_p=0.0024 [Nms/rad]	viscous damping coefficient as seen at the pendulum axis
η_g=1	planetary gearbox efficiency
η_m=1	motor efficiency
g=9.81 [m/s^2]	gravitational constant of earth
I_p = 0.0078838 [kgm^2]	pendulum moment of inertia
J_m = 3.9001e-007 [kgm^2]	rotor moment of inertia
K_g = 3.71	planetary gearbox gear ratio
K_m = 0.0076776	back electro-motive force (EMF) constant
K_t = 0.007683	motor torque constant
l_p=0.3302 [m]	pendulum length from pivot to center of gravity
M_c = 1.0731 [kg]	lumped mass of the cart system, including the rotor inertia
M_p = 0.23 [kg]	pendulum mass
R_m = 2.6 [Ω]	motor armature resistance
r_{mp} = 0.00635 [m]	motor pinion radius

Parameters of equations (1) and (2) are listed in the Table 1 with the values taken from [4, 5]. The linear equation of motion (3) and (4) are calculated after replacing in (1) and (2): cos(α) = 1 and sin(α) = α, and using the parameters in the Table 1.

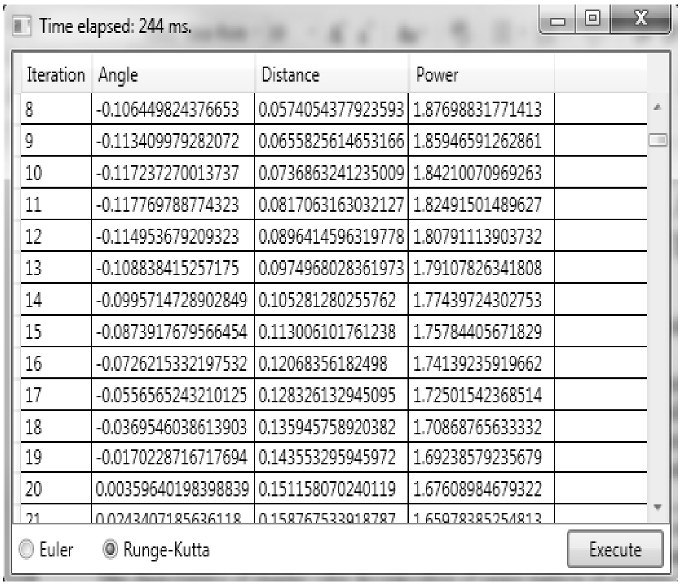
Euler and Runge-Kutta numerical methods are used for the integration of differential equations systems.

A fuzzy control schema of the gantry crane cart's position:

T-Controller is the FIS that uses fuzzy logic rules for an adequate assessment of the power that supplied to the input of the gantry crane [6]. Rules are formed on the formalization of knowledge and professional experience of the experts of certain industry.

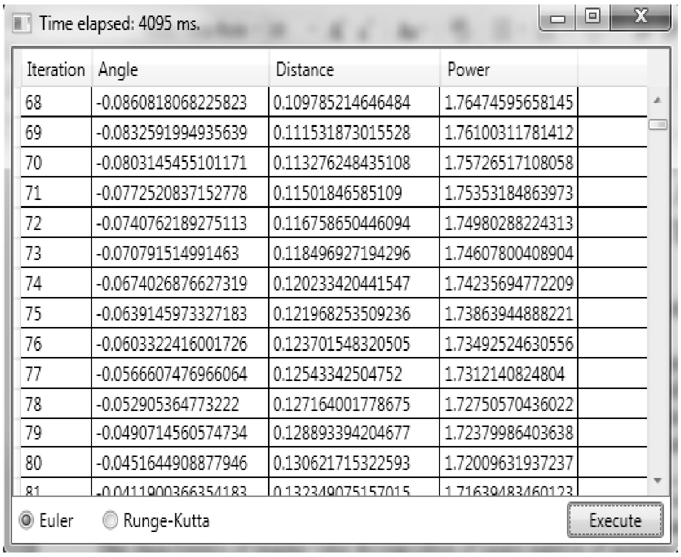
The synthetic model of object management (gantry crane) is presented on fig.3 based on Runge-Kutta method and fig.4 based on Euler method - fuzzy controller control system which might be used to rate the crane functionality with built-in swings reducing.

The swing manage is realized by controlling of the two main input parameters: the angle relative to the vertical axis of the cart is shown on screenshots below in the first column and cart position relative to the start/end point is shown in the second column, and one output parameter is calculated using T-Controller software and shown in the third column on the fig.3 and fig.4 screenshots.



Iteration	Angle	Distance	Power
8	-0.106449824376653	0.0574054377923593	1.87698831771413
9	-0.113409979282072	0.0655825614653166	1.85946591262861
10	-0.117237270013737	0.0736863241235009	1.84210070969263
11	-0.117769788774323	0.0817063163032127	1.82491501489627
12	-0.114953679209323	0.0896414596319778	1.80791113903732
13	-0.108838415257175	0.0974968028361973	1.79107826341808
14	-0.0995714728902849	0.105281280255762	1.77439724302753
15	-0.0873917679566454	0.113006101761238	1.75784405671829
16	-0.0726215332197532	0.12068356182498	1.74139235919662
17	-0.0556565243210125	0.128326132945095	1.72501542368514
18	-0.0369546038613903	0.135945758920382	1.70868765633332
19	-0.0170228716717694	0.143553295945972	1.69238579235679
20	0.00359640198398839	0.151158070240119	1.67608984679322

Figure: 3 System model based on Runge-Kutta method



Iteration	Angle	Distance	Power
68	-0.0860818068225823	0.109785214646484	1.76474595658145
69	-0.0832591994935639	0.111531873015528	1.76100311781412
70	-0.0803145455101171	0.113276248435108	1.75726517108058
71	-0.0772520837152778	0.11501846585109	1.75353184863973
72	-0.0740762189275113	0.116758650446094	1.74980288224313
73	-0.070791514991463	0.118496927194296	1.74607800408904
74	-0.0674026876627319	0.120233420441547	1.74235694772209
75	-0.0639145973327183	0.121968253509236	1.73863944888221
76	-0.0603322416001726	0.123701548320505	1.73492524630556
77	-0.0566607476966064	0.12543342504752	1.7312140824804
78	-0.052905364773222	0.127164001778675	1.72750570436022
79	-0.0490714560574734	0.128893394204677	1.72379986403638
80	-0.0451644908877946	0.130621715322593	1.72009631937237

Figure: 4 System model based on Euler method

To illustrate how system works and to assess the effectiveness of the developed solution, corresponding animation program was created, where time-lapse image changes are performed at regular intervals. Screenshot of this animation is displayed on fig.5 [7].

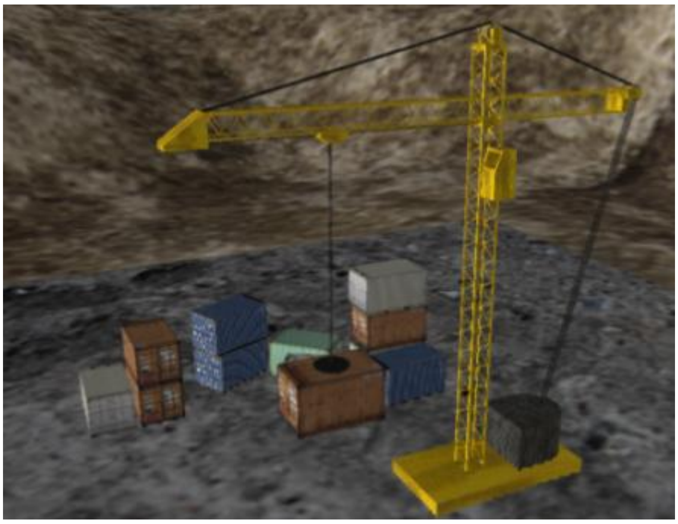


Figure: 5 System visualization

CONCLUSION

Gantry cranes are widely uses for industrial purposes where need to move the load from one area to another. In this case the load should be moved without any swinging because it may damage something around crane, especially people. Thus during this operation the load may fluently swings in pendulum-like trajectory. If proper swing exceeds the limit, it should be delayed or operation must be suspended until the time of swing do not stop. Any of these options takes away a lot of time, resulting in material damage.

In this research paper is presented control system of gantry crane cart swing with high accuracy positioning during movement. In addition operation of the system was visualized with animation.

The advantages and disadvantages of traditional fuzzy interference system were described. Although, T-Controller benefits were highlighted in comparison with traditional FIS.

Schema of simplified gantry crane model was introduced which based on two input parameters: angle and position, and one output power and one output parameter – power.

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