TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
AUTOMATIC CONTROL | AUTOMATYKA
3-AC/2013

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GANTRY AND BRIDGE CRANES NEURO-FUZZY CONTROL BY USING NEURAL-LIKE STRUCTURES OF GEOMETRIC TRANSFORMATIONS

NEURONOWO-ROZMYTE STEROWANIE SUWNICAMI BRAMOWYMI I POMOSTOWYMI Z UŻYCIEM STRUKTUR PRZEKSZTAŁCEŃ GEOMETRYCZNYCH O CHARAKTERZE NEURONOWYM

A b s t r a c t

Fuzzy logic is based on the use of natural language such as 'far or close', 'cold or hot' and etc. Its application range is very wide, from household appliances to the management of complex industrial processes. Many modern management tasks cannot be simply solved by classical methods because of the very great complexity of mathematical models. However, mathematical transformations are required for using the fuzzy logic theory on a computer and give a possibility to convert linguistic variables to their numerical value in the computer and vice versa. In this paper a gantry and bridge crane control system for managing carts swinging during transporting a load with high accuracy positioning during movement is presented. *T*-Controller fuzzy inference system as a base for crane management system is described and its main advantages in comparison with traditional systems are delineated. Schema of simplified crane model is introduced.

Keywords: *gantry and bridge cranes, fuzzy inference systems, T-Controller, simplified model of the crane system*

S t r e s z c z e n i e

Logika rozmyta bazuje na pojęciach języka naturalnego, takich jak „blisko lub daleko", „zimny albo gorący" itp. Zakres zastosowania logiki rozmytej jest bardzo szeroki, począwszy od prostych urządzeń gospodarstwa domowego, a skończywszy na zarządzaniu złożonymi procesami przemysłowymi. Wiele współczesnych zadań planowania i sterowania nie da się rozwiązać za pomocą klasycznych metod, ze względu na zbyt dużą złożoność obliczeniową modelowanych procesów. Wprawdzie przekształcenia matematyczne stanowią wymóg podczas komputerowej realizacji tego typu zadań, jednak podejmująca ją logika rozmyta daje możliwość konwersji informacji zakodowanych w języku naturalnym na odpowiadające im wartości numeryczne. Przedmiotem niniejszego artykułu jest system sterowania suwnicami bramowymi i pomostowymi dla zarządzania wózkami obrotowymi podczas transportu ładunku o wysokiej dokładności pozycjonowania położenia. Jako podstawę systemu zarządzania suwnicą przedstawiono system wnioskowania rozmytego za pomocą *T*-regulatora rozmytego, podkreślając jego zalety w porównaniu z tradycyjnymi systemami wnioskowania rozmytego. W artykule zawarto również uproszczony schemat modelu suwnicy.

Słowa kluczowe: *suwnice pomostowe i dźwigowe, system wnioskowania rozmytego, T-regulator, uproszony model mechanizmu suwnicy*

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1. Introduction

The most impressive feature of human intelligence is the ability to make correct decisions in conditions of incomplete and fuzzy information. Construction of the models that reflect human thinking and their use in computer systems today is one of the most important problems in science.

Artificial intelligence that easily copes with the tasks of managing complex technical objects was helpless in such simple situations. For creating intelligent systems that can adequately communicate with a person needed a new mathematical tool to translate controversial statements in the language of strict mathematical formulas. Fuzzy logic is very useful in cases of high accuracy and repeatable operations when people might be stuck or even not able to perform such operation.

Let we have crane and we need to carry some object from point to point in the shortest time. The main problem in moving object via crane is the emergence of swinging it that leads to performance degradation, increasing transportation time and reliability of gear could cause an accidents.

One of the ways to improve efficiency of process of a control system is based on the using of human experience and the fuzzy modeling that used controller based on fuzzy logic and allows considering the adverse effects, caused by system nonlinearities.

Therefore, it is necessary to predict and to provide measures for the suppression of these swinging. Then based on fuzzy model predict power that will be applied to the crane depends on elapsed distance and swinging angle to eliminate swinging at the destination point.

In this paper the gantry and bridge cranes control system has been presented. The simplified model of the crane is used to simulate the crane motion. Two widely known Runge-Kutta and Euler methods of the integration of differential equations systems were applied to the equation of the crane motion.

Common knowledge of crane operator was employed to supervise the crane movement on it's path from start to finish. Consequently, the fuzzy logic was used to convert operator's knowledge into understandable for computer language. As a result, the fuzzy rules were created and described using the following crane values like angle, positiona and power.

T-Controller fuzzy inference system was chosen among other systems as a base for crane management system. The reason is that the *T*-Controller system is more accurate because it is based on geometrical transformation model and much faster than Mamdani and Takagi-Sugeno systems because required less time to setup and configure the fuzzy inference system.

2. Gantry and bridge cranes management process

Gantry and bridge cranes in most cases used to transport load from one point to another. They raise one cart with flexible cables that are attached to the 'head' of the crane. The 'head' of the crane moves along the horizontal track. If a crane is climbed and starts moving, the cart begins to swing.

To solve this problem, there are two ineffective ways. One of them is to reach the end point, and then wait for the crane swinging reaches an acceptable level. However, it is definitely required too much time, especially taking into consideration the environmental conditions. Cart should be loaded and swapped out in a minimum time for economic reasons.

Another option is such as to pick up the cart and move so slow that swing was minimal. However, this could be used not on a windy day and nonetheless, this method takes too much time. An alternative is to create a crane, which will be used additional cables to correct the position of the cart during transporting. Nevertheless, very few cranes use it due to the higher cost of the solution.

For these reasons, the majority of cranes are still using people-operators to control engine power. Operator compensates external influence and sets the power simultaneously, so that the load reached their destination as soon as possible. This is no easy task, but an experienced operator is able to get good results.

In this paper the crane management system based on common experience of crane operator will be presented. The rules which operator use during his or her work were modified to comprehensible for computer language. These rules were written in form of fuzzy rules and used in *T*-Controller fuzzy inference system. Such approach gives a possibility to apply human common sense, knowledge and experience for solving everyday tasks without adequate mathematical model, for instance, air conditioning, climate control systems for commercial buildings such as offices, and household appliances like washing machines that can tell how large a load is or refrigerators that use fuzzy logic to cool different sections correctly. Moreover, another example of applying of fuzzy logic technology is traffic management where there is difficult to create any models of traffic, but IF-THEN logic can deal with vague expectations and respond to situations. The gantry and bridge cranes management system is realized to help people in their everyday work and is based on the same acquired human principles.

3. The simplified model of crane movement simulation

The simplified model of the crane is used to simulate the crane movements. The crane system is realized as pendulum model. It is shown on the Fig. 1.

The following characteristics are taken into account in this model: x_c is a position of the cart relative to the start 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.

If the cart is pushed it will move in a positive direction to the right and an angle of the pendulum will take a positive value and will move counter clockwise. In addition, the zero angle corresponds to the vertical position of the lower pendulum [5].

This single pendulum can be represented as a system with one input parameter *u* (the power of a crane) and two output: *a* (angle of the cart) and x_c (cart position).

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

$$\ddot{x}_c = \frac{-\left(I_p + M_p l_p^2\right) B_{eq}\cdot \dot{x}_c + \left(M_p^2 l_p^3 + l_p M_p I_p\right)\sin(\alpha)\dot{\alpha}^2 + M_p l_p \cos(\alpha) B_p \dot{\alpha}}{\left(M_c + M_p\right) I_p + M_c M_p l_p^2 + M_p^2 l_p^2 \sin^2\left(\alpha(t)\right)} + \frac{M_p^2 l_p^3 \cos(\alpha)\sin(\alpha) - \left(I_p + M_p l_p^2\right)\frac{\eta_g K_g^2 \eta_m K_t K_m \cdot \dot{x}_c}{R_m r_{mp}^2} + \left(I_p + M_p l_p^2\right)\frac{\eta_g K_g \eta_m K_t}{R_m r_{mp}} U_m}{\left(M_c + M_p\right) I_p + M_c M_p l_p^2 + M_p^2 l_p^2 \sin^2(\alpha)} \tag{1}$$

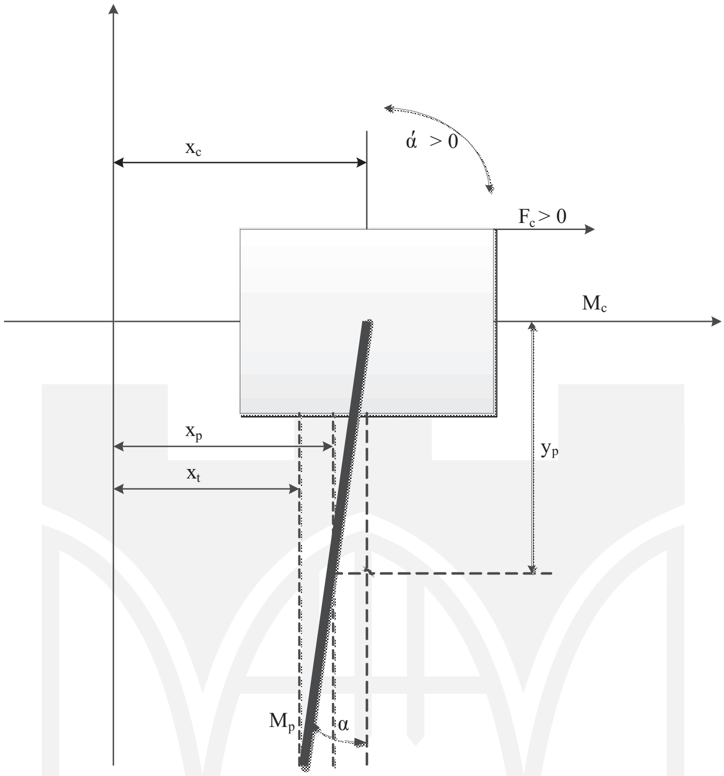


Fig. 1. The simplified model of the crane

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

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

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

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

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

Parameters of equations (1) and (2) are listed in the Table 1 with the values taken from [5, 6]. 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 [6].

Table 1

Parameters from (1) and (2) equations

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
$\eta_g = 1$	planetary gearbox efficiency
$\eta_m = 1$	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

Such widely known methods of the integration of differential equations systems like numerical methods of Adams, Bashforth, Hamming, Runge-Kutta and Euler can be applied to the equation of the crane motion. The latter two methods, namely Euler and Runge-Kutta were used in crane managment system to solve system of differential equations that represented in (3) and (4).

4. Traditional fuzzy inference systems and their advantages and disadvantages

Many modern management tasks cannot be simply solved by classical methods because of the very great complexity of mathematical models. However, mathematical transformations are required for using the fuzzy logic theory on a computer and give a possibility to convert linguistic variables to their numerical value in the computer and viceversa.

On the Fig. 2 the regions of most effective use of modern management techniques is shown. As can be seen, the classical control methods work well with fully deterministic control objects and deterministic environment. Fuzzy control methods are applied to systems with incomplete information and the high complexity of the control object.

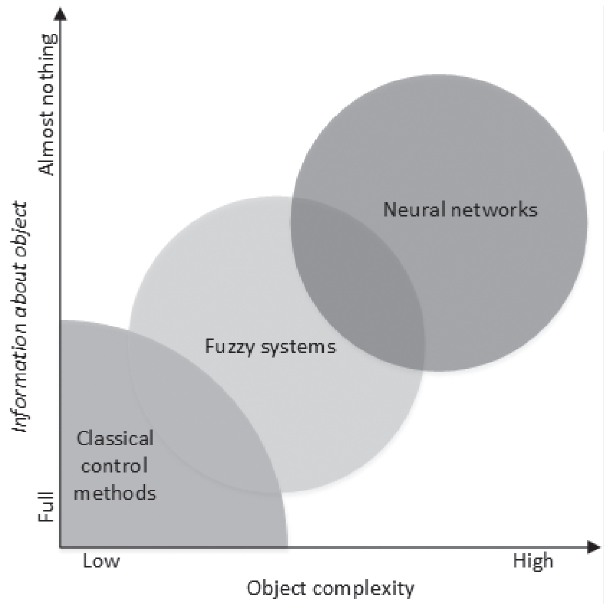


Fig. 2. Effective use of modern management techniques

Fuzzy inference system is a rule-based system that uses human common sense or expert knowledge to build a control system or model data. One of the FIS purposes is to extend of traditional data modelling and control methods.

Among traditional fuzzy inference systems algorithms the most famous and popular are Mamdani and Takagi-Sugeno algorithms, which, in particular, could be used to implement a system for the cranes cart operating.

The main advantages of Mamdani method are lack of standards in the rules constructing and fuzzy logic choice that based on experiments and extension expertise. This gives a possibility to describe the experience more intuitively and similarly to the human way. Mamdani algorithm has also the following common features as:

– Applicable when numerical data basis is incomplete and can be extended by human expert knowledge.

– Dependency on defuzzification method: same rules give different results depending on defuzzification function (Centre of Gravity, Minimum, First Maximum).
– Reasoning for defuzzification function choice based only on experiments.

Mamdani inference system is based on the following rule form: R: IF X IS A AND X IS B THEN Y IS C, where R is the rule number, X is the input number, A, B and C are linguistic variables, keyword IS marks a clause, keyword AND marks a conjunction.

Sugeno type FIS uses if sufficient number of basic numerical data is provided. It is effective in the calculation tasks and works good with optimization and adaptive methods that makes it widely used in the tasks of control. If the model parameters vary depending on the configuration and the nature or size of load then use of such fuzzy inference system is impractical because there is a need to create separate models for each of the partitioning area parts to form an appropriate control action, which can significantly affect the system performance.

As a result, traditional FIS include the following issues that affect the process:
– Good interpretability vs. good accuracy.
– Small number of input variables.
– Time consuming tuning.
– Dependency on defuzzification method: same rules give different results depending on defuzzification.
– Require sufficient data basis.

All of these issues limit the usage of the existing fuzzy systems for managing complex technical objects and there is a need to use another system that will compensate them.

One of the newly presented systems that compensate most disadvantages of traditional fuzzy inference systems is *T*-Controller.

5. *T*-Controller fuzzy inference system

T-Controller FIS is an original method of fuzzy logic. It is based on a geometrical data modeling conception (see Chapter 6).

T-Controller is a fuzzy controller – a way to create logical decisions for fuzzy logic system. It uses a fundamentally new method of defuzzification, which allows getting zero methodical error. *T*-Controller Workshop is an application that allows creating fuzzy controllers of *T*-Controller type using verbal user description and applies it to digital data [2].

T-Controller application is shown on the Fig. 3. The ‘Controller’ tab is opened on the screenshot that consist of ‘Input variables’, ‘Input variable membership functions’ and ‘Output variables’ sections. These sections will be described in more details further in this article. The next two tabs are ‘Data’ and ‘Results’. Data tab displays data from the uploaded file. On the Results tab a list of expected and predicted values after fuzzy processing is shown. This list could be saved to user’s PC. Additionally, the following errors like MAD (Median absolute deviation), MAPE (Mean absolute percentage error) and RMSE (Root-mean-square deviation) are calculated and shown on this tab.

T-Controller Workshop as the application provides three working modes:
1. Creation and replacing of controller, using user’s linguistic description.
2. Controller creation with table data.
3. Controller usage with real data.

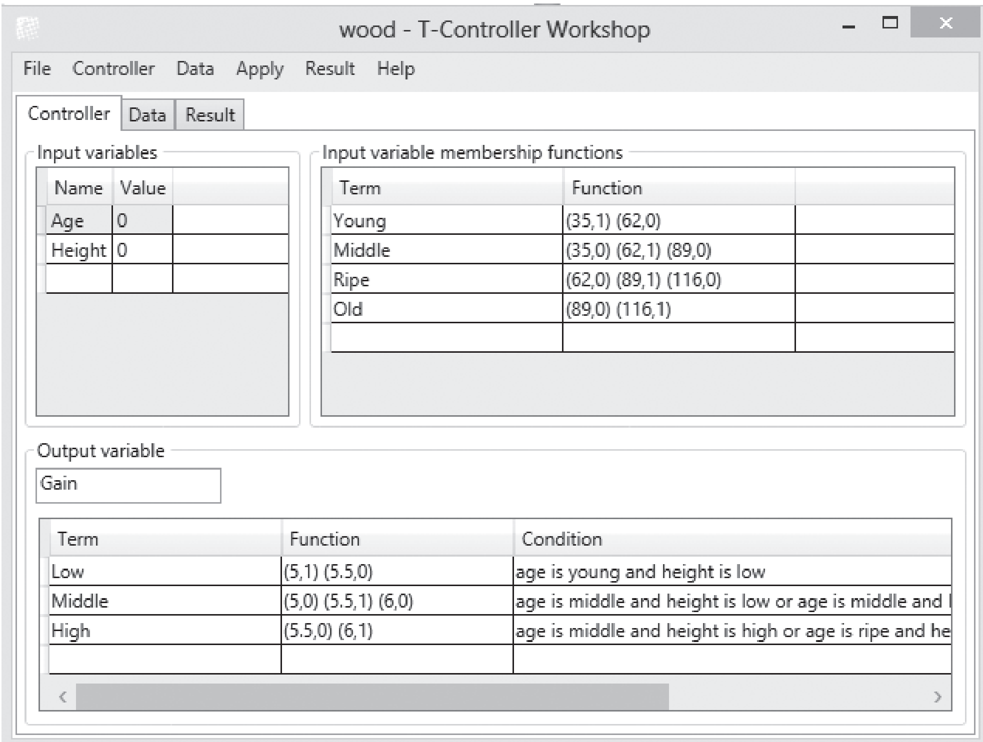


Fig. 3. *T*-Controller application

5.1. Input variables settings

In order to create controller it is required to set all inputs (input variables), which are used by controller. These values are set in column 'Name' of the table 'Input Variables'. New inputs can be added with mouse double click at an empty table row.

Input values used when controller is applied in a single predict mode and should be filled in.

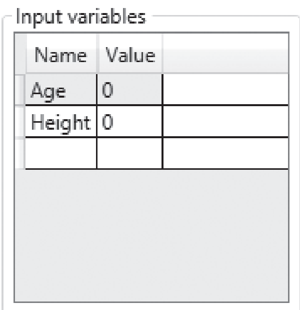


Fig. 4. Controller input settings

The next step is to assign a membership function for each input. In order to do this appropriate name from the table 'Input Variables' should be selected. Linguistic variable names for this input and appropriate membership functions are shown on the Fig. 4 and Fig. 5.

To define input variables membership function it's required to set 2 parameters:

1. Linguistic variable that defines this function in column 'Label'.
2. Coordinates of polyline, which describes this membership function. The coordinates are assigned in text format as a set of tuples and are set in the column 'Function'.

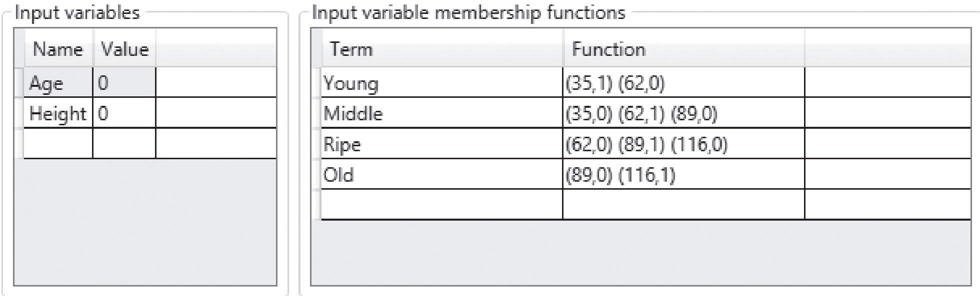


Fig. 5. Controller input and appropriate membership functions

5.2. Output variables settings

T-Controller has one output variable by definition. It is described by name, list of membership functions and by the condition, how this point belongs to output variable ranges. These conditions is also called as fuzzy logic rules because they are based only on linguistic terms, which describe input variables.

5.3. Fuzzy logic rules construction

Conditions and rules of fuzzy logic is set as a text in column ‘Condition’ and row which relates to appropriate output variable range. Fuzzy logic rule consists with assertions in following form:

Assertion: = <input name> is <linguistic variable of this input>

Assertions are united between themselves with conjunction by operator ‘AND’.

Conjunction: = <assertion> and <assertion>

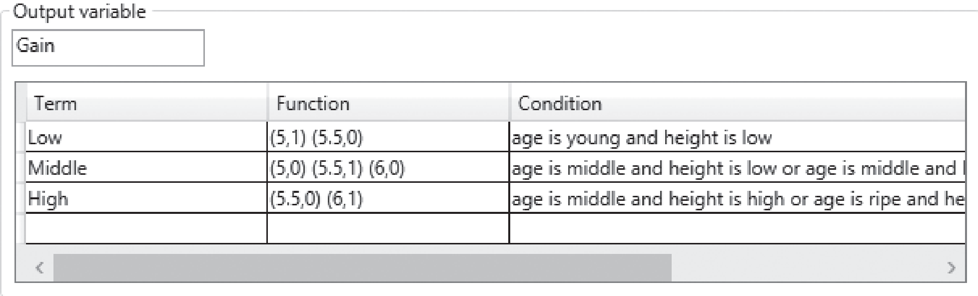
Conjunctions are united between themselves in conditions (disjunctions) by operator ‘OR’.

Condition: = <conjunction> or <conjunction>

Therefore, each linguistic range of appropriate output variable has just one dependency function and one condition, which defines entering to this range, Fig. 6.

5.4. Data loading

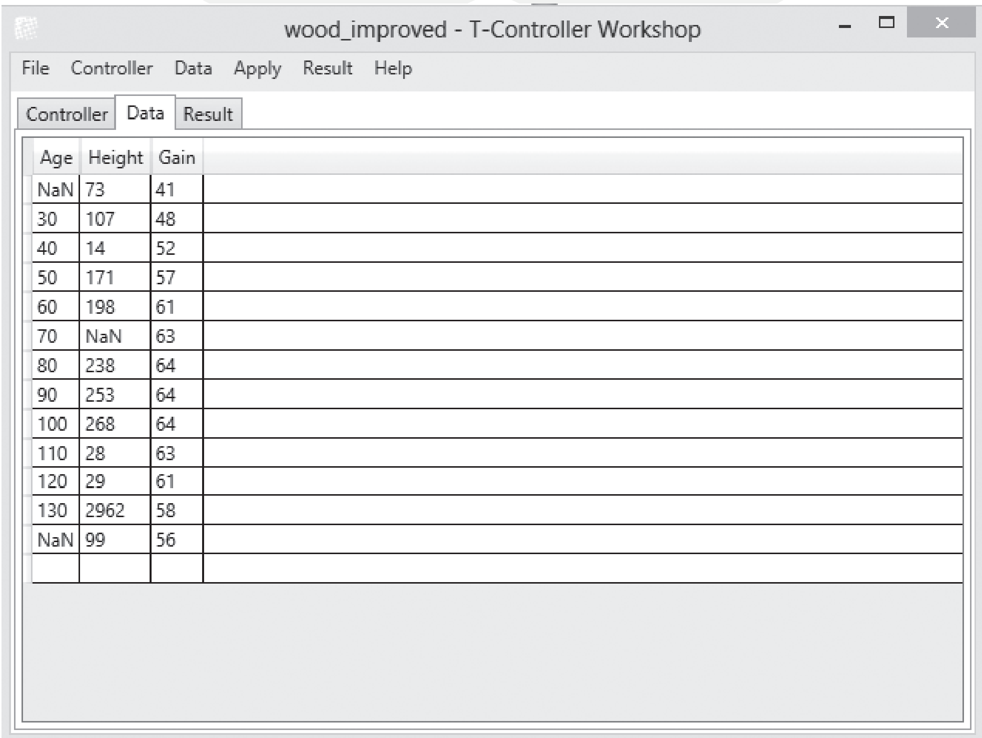
T-Controller Workshop works with data in text format CSV. It’s assumed that first row in data file contains table column names, which is stored in this file.



Term	Function	Condition
Low	(5,1) (5.5,0)	age is young and height is low
Middle	(5,0) (5.5,1) (6,0)	age is middle and height is low or age is middle and l
High	(5.5,0) (6,1)	age is middle and height is high or age is ripe and he

Fig. 6. Output parameters

Data set also can contain skipped values. Such values are marked as 'NaN' and controller will work with not completed data set. It's shown in following Fig. 7.



Age	Height	Gain
NaN	73	41
30	107	48
40	14	52
50	171	57
60	198	61
70	NaN	63
80	238	64
90	253	64
100	268	64
110	28	63
120	29	61
130	2962	58
NaN	99	56

Fig. 7. Loading incomplete data set

5.5. *T*-Controller advantages

T-Controller has such advantages over traditional FIS:

– 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. *T*-Controller uses the following rule form: R: IF X IS A AND X IS B THEN Y IS C, where R is the rule number, X is the input number, A, B and C are linguistic variables, keyword IS marks a clause, keyword AND marks a conjunction;
– High accuracy of *T*-Controller – high-speed geometrical defuzzification method with zero systematic error (much strict «input» gives much precise «output»);
– The procedure of configuration is faster;
– Simplicity of implementation in both software and hardware version.

6. Geometrical transformation model

The GTP is totally a new concept of the information objects modeling that are presented either tabular data or production rules of the logical conclusions and their combinations. The GTM is intended for applying in the 'black box' or 'gray box' mode and provided an effective solution for a wide range of problems such as classification with and without the supervisor modes, the time series prediction and forecasting, the main components analysis and factor analysis, the partially lost data or their consolidation recovering, the information protecting and privacy methods implementing and solving the systems of the linear algebraic equations with not defined and redefined systems and multidimensional data visualization [7].

Geometrical transformation model (GT) is universal approximator that realizes training and self-training principles. It is based on the space and time paralleling realized both by hardware and software manners. GT is assigned to remove or reduce negative properties of existing means of information modeling, such as regressive and inductive models, artificial neural networks, usual fuzzy logic controllers and static procedures [9].

Geometrical transformation model has the following properties:
– Quick feed-forward training for previously set number of computational steps that allows both to solve multi-dimension tasks and guarantee the reproducibility of training results;
– Possibility to receive satisfactory solutions on low dimensional training data;
– Possibility to solve tasks in unattended mode;
– Possibility to analyze of inner data structure;
– High precision and improved generalizing properties;
– Effective solution of tasks of computing mathematics (solving of equation systems);
– Simple variants of solution of fuzzy logic and neural network tasks [3].

6.1. Basic suppositions of geometrical transformation model

Information models are based on the use of the available experimental database by definition. Let's abstract from the obvious problems which may occur during its creation, including the presence of hidden parameters, noises, the ambiguity of data, contradictory of certain dimensions, different density and probability of representation of data in certain planes of the domain. Let's assign the above features to the factors that increase the general error of the modeling. Influence of these features may be minimized by the usage of the additional methods for increasing the accuracy. In other words, consider that the modeling object functions are sufficiently represented by the set of the vectors of realizations (observations), generally – cardinality of the continuum. The separation of vector on input and output parameters (attributes) is not essential for the GTM. Each of the vectors is displayed as a point of of the multidimensional space of realizations. There intuitively exist space-similar relations between the elements of this space such as: the concept of the norm or distance from the point to the origin, as well as the metrics for establishing proximity between the implementations. The selected structure of the space realizations determines the way of the comparison and possible transformations of implementations.

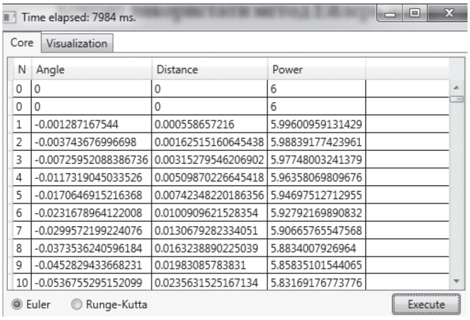
Taking into consideration the option the Euclidean space realizations as a linear space over a number field for which there exists a scalar product operaton in this field. Note that there exist as the relationship between the individual parameters of vector realizations as relationships between realizations. Then points of the observations of the modeling object are forming his body (hyperbody). This body will have a definite dimension and form depending on the characteristics of the data. Hyper body is characterized by the compactness property where close realizations correspond to the points which are located close in space.

In the absence of linkages, modeling objects body becomes amorphous form and operations of simulation lose all practical meaning. The concept of GTM provides an approximation of certain geometric transformation of the set of available points of modeling objects body implementation, which representing in the aggregate state sample for training and testing. The above transformations that are performed both in training and applying the model, implement specified functions of GTM – consolidation by presenting the body with minimal loss in the coordinate system of reduced dimensions, analysis of PCA and FA by constructing an intermediate coordinate system, orthogonal directions along the last match of the directions of maximum variance, finding of the unknown coordinates of points based on the known projection onto the plane of inputs etc. As a basic geometric transformations of the body object modeling points elected sequential construction of normal (up to a given vector) space (hyper-space) and projection of implementation points onto constructed normal sapce. For these transformations applied formulas expansion for 3D analytic geometry on a space of arbitrary dimension.

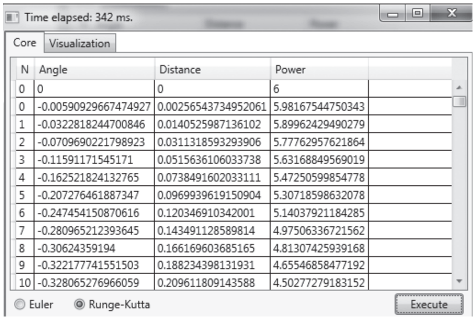
7. Crane management system based on *T*-Controller

Industrial cranes are used for transportation of load within a given trajectory. 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 [8].

The swing manage is realized by controlling of the two main input parameters: the angle relative to the vertical axis of the cart and cart position relative to the start/end point, and by using *T*-Controller software. *T*-Controller is the FIS that uses fuzzy logic rules for an adequate assessment of the power that supplied to the input of the crane. Rules are formed on the formalization of knowledge and professional experience of the experts of certain industry. The generated data by Euler and Runge-Kutta methods are submitted on the Fig. 8.



N	Angle	Distance	Power
0	0	0	6
0	0	0	6
1	-0.001287167544	0.000558657216	5.99600959131429
2	-0.003743676996698	0.00162515160645438	5.98839177423961
3	-0.00725952088386736	0.00315279546206902	5.97748003241379
4	-0.0117319045033526	0.00509870226645418	5.96358069809676
5	-0.0170646915216368	0.00742348220186356	5.94697512712955
6	-0.0231678964122008	0.0100909621528354	5.92792169890832
7	-0.0299572199224076	0.0130679282334051	5.90665765547568
8	-0.0373536240596184	0.0163238890225039	5.8834007926964
9	-0.0452829433668231	0.01983085783831	5.85835101544065
10	-0.0536755295152099	0.0235631525167134	5.83169176773776



N	Angle	Distance	Power
0	0	0	6
0	-0.00590929667474927	0.00256543734952061	5.98167544750343
1	-0.0322818244700846	0.0140525987136102	5.89962429490279
2	-0.0709690221798923	0.0311318593293906	5.77762957621864
3	-0.11591171545171	0.0515636106033738	5.63168849569019
4	-0.162521824132765	0.0738491602033111	5.47250599854778
5	-0.207276461887347	0.0969939619150904	5.30718598632078
6	-0.247454150870616	0.120346910342001	5.14037921184285
7	-0.280965212393645	0.143491128589814	4.97506336721562
8	-0.30624359194	0.166169603685165	4.81307425939168
9	-0.322177741551503	0.188234398131931	4.65546858477192
10	-0.328065276966059	0.209611809143588	4.50277279183152

Fig. 8. Generated data by Euler and Runge-Kutta methods

7.1. Linguistic control strategy

On the other hand, the human operator is able to operate a crane without differential equations. The operator did not use the cable lengths sensor. The operator lifts the cart by means of a crane, applies middle power to the crane, to see how the cart is swinging. Depending on the response, he adjusts the engine power to keep the cart a little behind the cranes 'head'. In this position, the maximum speed can be achieved with minimal impact. Toward to the end position, the operator reduces engine power. Thus, the cart gets a little ahead of the cranes 'head' and cart almost reaches the desired location. Then increase engine power so that the 'head' of the crane is above the object while swinging is close to zero. In this case there is no differential equations required to implement this, and all sorts of non-linearity and offsets are eliminated by operators observations for the position of the cart.

Analysis of operator's actions show that the operator uses some 'rules of thumb' to describe his management strategy:

– Start with a medium power.
– If you're still far from the destination point, then adjust the engine power so that the cart has become a little more far for the 'head' of the crane.
– If you are close to the destination, it is necessary to reduce the speed so that cart got a little ahead of the cranes 'head'.
– When the cart is very close to the destination, provide the minimum engine power.
– When the cart has reached its destination and swinging is zero, turn off the engine.

7.2. Implementation of linguistic control strategy

To automate the crane control sensors to determine the position of the cart 'Distance' and its inclination angle 'Angle' are used. Using these inputs to describe the current state of the crane, six rules that can be translated to 'if-then' format are defined:

1. IF Distance = far AND Angle = zero, THEN Power = positive medium.
2. IF Distance = far AND Angle = negative low, THEN Power = positive big.
3. IF Distance = far AND Angle = negative big, THEN Power = positive medium.
4. IF Distance = medium AND Angle = negative low, THEN Power = negative medium.
5. IF Distance = small AND Angle = positive low, THEN Power = negative medium.
6. IF Distance = zero AND Angle = zero, THEN Power = zero.

‘If-then’ rules always describe the reaction to certain situations: if <situation> then <action>.

In the case of a crane control system, each situation is determined by two conditions. The first term describes the distance value, the second the angle value. Terms are combined by ‘AND’, which indicates that both conditions must necessarily be carried out for that situation.

8. Conclusion

Today, fuzzy logic items can be found in many industrial products such as electric trains control systems or military helicopters appliances. Active fuzzy logic consumers are the bankers and financiers, as well as experts in the field of political and economic analysis, which everyday tasks require to make the right decisions in difficult circumstances of unpredictable market. They use a fuzzy system to create models of various economic, political and stock situations.

The following advantages of fuzzy systems could be outlined:

1. Ability to handle input data set clearly: for example, dynamic problem when data continuously change over time, value that’s impossible to specify uniquely as results of statistical surveys or advertising campaigns;
2. Ability to formalize fuzzy evaluation criteria and comparison: operating ‘most’, ‘possible’, ‘preferably’ and etc. criteria;
3. Ability to conduct quality evaluations as input data and output results: data values and their degree of certainty and its distribution;
4. The possibility of fast simulation of complex dynamic systems and their comparative analysis with a given degree of accuracy, in terms of the system behavior principles described by fuzzy-methods: quickly find the exact values of the variables and make rules to describe them and evaluate various options for output values.

Logistics systems give a possibility to use the experience and the results of experiments to provide much effective solutions for many widespread problems. They do not replace nor compete with traditional control methods. Fuzzy logic extends the ways of implementation of automated control methods that are used in applications and adds the ability to use observations in system management. A simple example is a gantry and bridge cranes that use fuzzy inference system can provide a clear and simple solution to the problem that much more difficult to be solved using traditional management methods.

The use of automated systems for solving everyday tasks enables us to save our time and money. The use of automated control systems to control crane cart swinging avoids the company form unexpected losses that may occur if the crane operator exhausted or sleepy and cannot notice the changes in the system. Ensuring the quality and speed of load transportation saves the company money and raises its rating among others. Therefore, the use of automated management systems in industry is entirely appropriate.

In this paper the automated control system based on the fuzzy logic is presented. The crane management system control cart swings with high accuracy positioning during movement. The simplified model of the crane is 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). New fuzzy inference system *T*-Controller based on geomatrical transformation model is used to realize the crane management system. Geometrical transformation model is briefly described and it's main properties are listed.

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