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THE DESIGN OF A SYSTEM TO CONTROL THE STABILITY OF A FORKLIFT

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Summary. This paper discusses how to design a system to establish the stability of a forklift working with different weights using fuzzy logic and modern information technologies.

Key words: forklifts, stability, stacking of the load, fuzzy logic, radio frequency identification (RFID).

INTRODUCTION

The most common problem in the use of a forklift is the problem of stability and particularly the issue of stability under load. As a consequence there are a large number of accidents that lead to the loss of loads, damage of forklifts and injury to operators.

The need for solving this problem of forklift stability occurs mainly in a number of different circumstances such as: when the forklift is moving on uneven surfaces, while turning on a tight radius, accelerating and braking, at the beginning and end of lifting or lowering, maneuvering the forklift, when lifting a tall stack loaded on the forks, when unloading, when the angle of the chassis of the forklift to the load is a maximum, when the forklift is angled on an adverse camber and when the forklift is braking suddenly from high speed.

The stability of wheeled lifting machines is empirically ascertained by manufacturer as part of the certification process. During certification of every model of wheeled lifting machines the transportation and lifting characteristics of the device are tested and defined and the limits of the operational capabilities and the boundary conditions of use are measured.

Whilst the parameters of the forklift performance can be tested and specified, the characteristics of the loads are variable and cannot be completely defined or tested; they can be very different from the standard load used in certification.

The solution to this problem is traditionally associated with the measurement of coefficient of longitudinal and lateral stability in motion and stacking of the load [1].Using stability coefficients is the most common way of determining stability in technical applications, but it should be noted that there are many ways to solve this problem by analytic methods [2]. The main drawback of the above methods is the lack of a way to automatically identify the loads for the purposes of calculating the stability coefficients required by the stability calculations and the need for the testing of a variety of loads which significantly limits the usefulness of analytical methods in real world conditions.

RESEARCH OBJECT

A solution to this problem is the use of radio frequency identification (RFID) tags consisting of a central processing unit (CPU) with memory and scanners for reading and writing these tags connected to a mobile device or an embedded computer on the forklift with the appropriate programming.

The key of the solution thus lies in the creation of the mathematical algorithms and the implementation of those algorithms in software allowing the collection of information about the load on reception from the on load RFID tag and, along with the information about the forklift, the calculation of the boundary conditions for the forklift for any load. This is then available via the mobile device or on embedded computer as a set of restrictions on lifting and transporting.

The generation of algorithms for this process is solved through fuzzy analysis of the stability coefficients.

Consider the general problem of the formalization of stability control of a forklift using fuzzy logic:

RESULTS OF THEORETICAL RESEARCH

We introduce the concept of fuzzy control system (FCS). Let *X* be the set of control strategies and *Y* be the set of control objects. Let us define a mapping *u*which we will call the ratio of fuzzy control. The tuple $S = \langle X, Y, \eta \rangle$ will be called the type of fuzzy control; the group of three $I = \langle X, V, \eta \rangle$, where the V is a finite subset of the multiple *Y,* will be called the assignment of fuzzy control (FCS) of the type *S*, and we will assume that $I = \langle X, V, \eta \rangle$ shows that for an arbitrary number $c \in [0,1]$, which reflects the value of membership function and an arbitrary control strategy $x \in X$ we select all those and only those control objects $y \in V$, such that the function itself will be $\eta(x, y) \geq c$.

Let us add the concept of fuzzy functional graph of control, which plays an important role in the synthesis of fuzzy model as a mechanism for logical structuring.

Let $F = \{f_a \mid f_a : X \rightarrow [0,1],\ a \in A\}$ be the basic set of fuzzy membership functions of *X,* where *A* is a set of fuzzy variables.

The concept of fuzzy functional graph of control (FFGC) over a basic set of *F* is defined as follows: In the finite multipolar oriented network we select a pole which is called the root.The remaining poles are called leaves and they are assigned to objects of *Y,* where different leaves can be assigned to the same record. Edges are assigned functions from the set *F.* Thus the loaded multipolar oriented network which we call FFGC is defined for a basic set of *F.*

The function of FFGC is determined in this way. Let us call theconductivity of the edge of FFGC the function, which is equal to a membership function, assigned to this edge; we will call the conductivity of an oriented chain of edges of FFGC the function, equal to the minimum conductivity of a chain of edges; we will call the filter function of the

β peak of FFGC (which is defined $\varphi_\beta(x)$ the membership function equal to the maximum functions of the conductivity of the oriented chains leading from the root to the β peak. We assume that the object β which is assigned to an edge, falls in response of FFGC to control strategy $x \in X$ $\varphi_a(x) \geq c$ for the number *c,* (i.e. there is a max-min-composition of membership function). The response of FFGC to *U* to the control of *x* for the number $c \in [0,1]$ is called the set of objects, that have come in response of FFGC to the control strategy of *x* for the number *c* and we will define it as $J_U(x,c)$. This membership function $J_U(x,c)$ will be considered the result of the functioning of FFGC of *U.*

Say that FFGC of *U* is allowable for FCS, if for any control strategy $x \in X$ and any number *c* is satisfied by $J_U(x,c) = \{y \in V : \eta(x,y) \geq c\}$. We will detail our solution to create FFGC problem of controlling the stability of the forklift.

We will define a list of input fuzzy variables:

X_1 - Weight of the load,

X_2 - Weight of the loader.

X_3 - Height of the center of gravity of the loader,

X_4 - Height of the center of gravity of the load,

X_5 - Depth of the center of gravity of the loader,

X_6 - Depth of the center of gravity of the load,

X_7 - Distance of the center of gravity of the loader from the line of lateral tilting,

X_8 - Distance of the center of gravity of the load from the line of lateral tilting,

X_9 - Speed of the loader,

X_{10} - Turning radius of the loader,

X_{11} - Deceleration of the loader,

X_{12} - Longitudinal angle of the loader in motion,

X_{13} - Longitudinal angle of the loader when stacking,

X_{14} - Lateral angle of the loader when stacking,

X_{15} - Lateral angle of the loader in motion.

The list of initial fuzzy variables is as follows:

Y_1 - Safety factor of the longitudinal stability while stacking,

Y_2 - Safety factor of longitudinal stability in motion when loaded,

Y_3 - Safety factor of lateral stability while stacking,

Y_4 - Safety factor of lateral stability in motion when loaded.

To construct FFGC problem of controlling the stability of the forklift (Figure 1), consider the following dependences (the filter function of the peaks $\varphi_\beta(x)$:

$$Y_1 = \varphi(x_1, x_2, x_3, x_4, x_5, x_6, x_{13}),$$

$$Y_2 = \varphi(x_1, x_2, x_3, x_4, x_5, x_6, x_{12}, x_9, x_{11}),$$

$$Y_3 = \varphi(x_1, x_2, x_3, x_4, x_5, x_6, x_{14}),$$

$$Y_4 = \varphi(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_{15}, x_9, x_{10}) \quad .$$

For this case, assume that all fuzzy variables are linguistic variables with the following terms:

$\{Y_{1i}\}$ - the set of terms of the linguistic variable Y_1,

$\{Y_{2i}\}$ - the set of terms of the linguistic variable Y_2,

$\{Y_{3i}\}$ - the set of terms of the linguistic variable Y_3,

$\{Y_{4i}\}$ - the set of terms of the linguistic variable Y_4,

$\{X_i\}$ - the set of terms of the linguistic variable X_i .

The number of terms for the above linguistic variables may be different. With the assistance of the concept of general multiple number and membership functions consider each of the terms as a fuzzy multiple number as follows:

$$Y_{1i} = \int_{Uy1} \varphi^{y1i}(v_{y1}) / v_{y1}, v_{y1} \in U_{y1};$$

$$Y_{2i} = \int_{Uy2} \varphi^{y2i}(v_{y2}) / v_{y2}, v_{y2} \in U_{y2};$$

$$Y_{3i} = \int_{Uy3} \varphi^{y3i}(v_{y3}) / v_{y3}, v_{y3} \in U_{y3};$$

$$Y_{4i} = \int_{Uy4} \varphi^{y4i}(v_{y4}) / v_{y4}, v_{y4} \in U_{y4};$$

$$X_i = \int_{Uxi} \mu^{xi}(x_i) / x_i, x_i \in U_{xi};$$

Where $U_{y1}, U_{y2}, U_{y3}, U_{y4}, U_{xi}$ - the general sets for which the linguistic variables Y_1, Y_2, Y_3, Y_4, X_i are given.

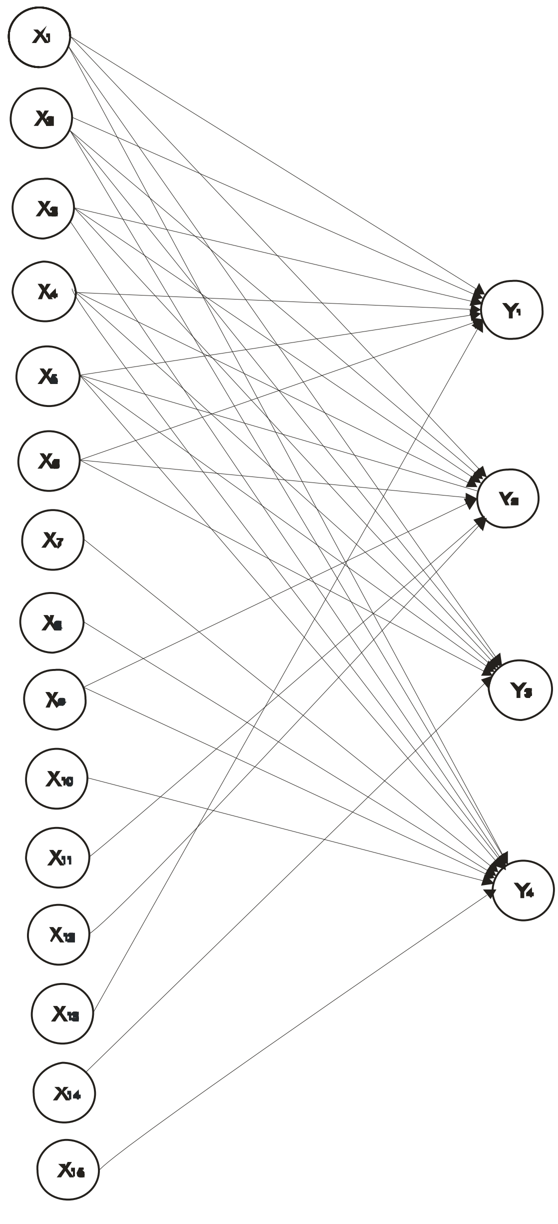

Fig. 1. Fuzzy functional graph of controlling the stability of the forklift

To create a base of fuzzy logic inference rules, which form the basis of the knowledge base for the automated workstation for the forklift operator, it is necessary to construct logical expressions of the relationships of input and output linguistic variables of the following type.

For the longitudinal stability when stacking:

$$IF(X_1 = X_i)AND(X_2 = X_i)AND(X_3 = X_i)AND(X_4 = X_i)AND(X_5 = X_i)$$
$$AND(X_6 = X_i)AND(X_{13} = X_i)THEN(Y_1 = Y_{1i})$$

For longitudinal stability in motion when loaded:

$$IF(X_1 = X_i)AND(X_2 = X_i)AND(X_3 = X_i)AND(X_4 = X_i)AND(X_5 = X_i)$$
$$AND(X_6 = X_i)AND(X_9 = X_i)AND(X_{11} = X_i)AND(X_{12} = X_i)THEN(Y_2 = Y_{2i})$$

For lateral stability when stacking:

$$IF(X_1 = X_i)AND(X_2 = X_i)AND(X_3 = X_i)AND(X_4 = X_i)AND(X_5 = X_i)$$
$$AND(X_6 = X_i)AND(X_{14} = X_i)THEN(Y_3 = Y_{3i})$$

For lateral stability in motion when loaded:

$$IF(X_1 = X_i)AND(X_2 = X_i)AND(X_3 = X_i)AND(X_4 = X_i)AND(X_5 = X_i)$$
$$AND(X_6 = X_i)AND(X_7 = X_i)AND(X_8 = X_i)AND(X_9 = X_i)AND(X_{10} = X_i)AND(X_{15} = X_i)THEN(Y_4 = Y_{4i})$$

Accordingly, the completed knowledge base consists of SQL-procedures, inference rules, and SQL-tables with information about the load and the forklift.

CONCLUSION

Thus the system of monitoring and controlling the stability of the forklift has a fairly wide range of applications.This is explained primarily by the fact that it is designed as a general method of creating a "virtual instrument" decision support system for an operator for any (especially the "low cost") model of the loader. A different application of the proposed method is to use microcontroller and servo to control the stability of the forklift when working with variable loads which will enable an even wider set of use cases.

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МЕТОДИКА СОЗДАНИЯ СИСТЕМЫ УПРАВЛЕНИЯ УСТОЙЧИВОСТЬЮ ВИЛОЧНОГО ПОГРУЗЧИКА

Кичкин А.В., Кичкина Е.И.

Аннотация. В статье рассмотрена методика создания системы устойчивости вилочного погрузчика при работе с различными весогабаритными грузами на основе нечеткой логики и современных информационных технологий.

Ключевые слова: вилочные погрузчики, управление, система устойчивости, весогабаритные грузы, нечеткая логика, информационные технологии.