PRELIMINARY DESIGN STUDY OF A FUZZY TRACKING CONTROLLER APPLIED TO A CRANE TYPE MANIPULATOR

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Abstract. The main purpose of a control system is usually to force the output to follow a reference input with zero steady state error while satisfying certain transient requirements such the settling time for rapid following, overshoot and smoothness of the transient response. This paper is concerned with finding a fuzzy rule-based controller achieved by learning from a virtual feedback (PID) controller capable for satisfying rapid following, zero steady state error and overshoot suppression applied to robotized manipulators dedicated to heavy loads or big container handling.

Keywords: Rapid following, Fuzzy tracking controller, Virtual training,

1. Introduction

Shipboard load manipulation, Robotization in building construction, civil engineering, tunnelling, mining and dock cranes cover various classes installed on civil construction industries, such as pedestal cranes, shipboard container cranes and granty types. For instance, offshore cranes work in open sea conditions and their lifting capacities may reach up to several thousand tons. These heavy lift cranes work on oil fields in the open sea and their demand is directly linked to offshore oil activity. Container cranes represent the most significant area of harbour cranes. The growth of containerisation in world trade keeps up a steady flow of new investment nearly all over the world, currently in use in many areas and ways.
Taking this type of cranes as a group, and specially the heavier ones of the range, one can find things which are typical in each. Although these types of cranes serve in various environments and are being used by different types of industries, they bear certain similarities.

It would seem that the most significant technical changes will happen in the electrical field because in special cranes there are two main areas: firstly motors and drives, and secondly man-machine interface, automation (or semiautomatic)(Thomas et all 1992)[1]. In drive units the regulation of electric motors is advancing very rapidly both in dc and ac, and speed or position control will not be a problem at all. It seems that the only reason why the advanced thyristor controls or inverted drives are not so commonly accepted is a certain conservatism among the crane users. However, after a few years time these advanced computer-controlled digitalized drives will be found in most new large cranes of this type.

Automation of big cranes and development of man-machine interface is an area where certain conservatism should be used. Almost all of the lifting processes are so complicated that they cannot be easily automated or robotized. However, semi-automation of most processes is possible and should be applied to save labour especially where cycle times are long or monotonous. The man-machine interface is an area where rapid development appeared and applied technology is being implemented.

The need to increase the operational speed while keeping steady state error avoiding overshoot is the main purpose of this work, not only to track a desired path but also to perform fully automated operations in the task of handling containers, bulk material, general cargo or heavy lifts mainly in civil construction and harbour industry applications (Lauri et all 1992)[2].

2. Problem statement

The main topics of the proposed fuzzy control developing task comprises the following automated steps:

- On line identification of the system parameters under some priori knowledge about model structure.
- Adaptive virtual controller design. (PID) controller)
- Training a fuzzy rule-based controller
- On-line application of a fuzzy rule based path-tracking controller

2.1 System identification

As the crane equation model is known, only its parameters must be achieved. The model is described as

$$\frac{d^2Y_o}{dt^2}+\frac{G}{L}Y_o=\frac{G}{L}Y_i \qquad (1)$$

where Yo is the actual position of crane load, Yi is the actual position of the manipulator, G is a constant parameter denoting the gravity acceleration and L is the length of cable. The only relevant parameter in this equation is L, which is varying during the crane operation [6]. In figure 1. it is shown the crane configuration.

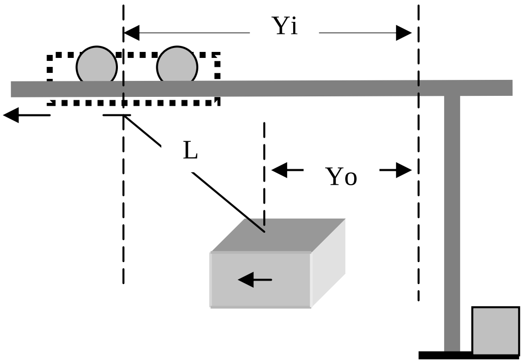

Fig. 1. The crane configuration

A servomotor responsible of supplying the manipulated variable with time constant of two seconds follows the fuzzy controller. The control loop arrangement is shown in figure 2.

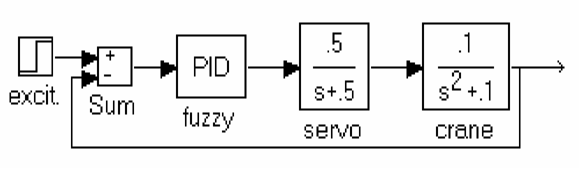

Fig. 2 Control loop structure

2.2 Virtual controller design

The purpose of this controller is to serve as a trainer in the task of achieving a fuzzy rule-base to apply as fuzzy rule based controller on the crane.

The virtual controller (suboptimum) that satisfy the requirements on the crane dynamics (increase the operational speed while keeping reduced steady state error avoiding overshoot) is shown in table I

Table I. Parameters of the virtual controller as function of the length of cable.

Kp	**Ti**	**Td**	**L (m)**
4	8	3	100
3	6	3	50
2	4	3	25
1	3	3	12

Such virtual controller has been achieved by the ATV autotuning technique or relay feedback autotuning, which supply the frequency of the limit cycle and its associated gain, known as ultimate frequency and ultimate gain [5].

With such values, the virtual controller parameters were computed.

2.3 Training a fuzzy rule based controller

The fuzzy rule base is achieved by mapping the virtual controller input/output variables. Its structure is shown in figure 3 [3,4].

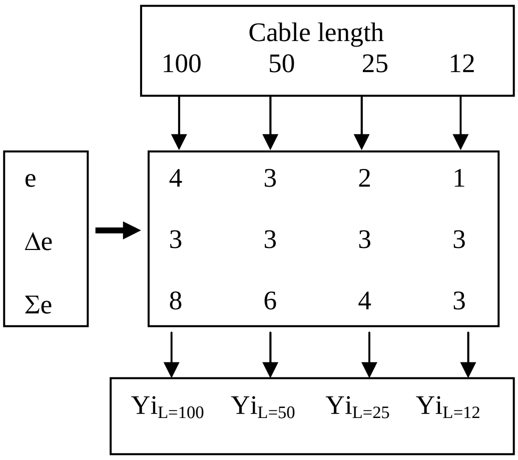

Fig. 3. Structure of virtual controller mapping

The mapping task is subjected to the membership function definition in such a way that the resultant rule base dimensions depends on the number of membership functions selected. Three membership functions for the input variables of error (e), increment of error (Δe), integral of error (Σe.) and four membership functions for the length (L) of cable are necessary. Under this conditions the mapping procedure generates a rule base of

$$3 \times 3 \times 3 \times 4 = 108 \text{ rules}$$

In the case of four membership functions for every input variable the rule base is

$$4 \times 4 \times 4 \times 4 = 256 \text{ rules}$$

A practical alternative to avoid the task of defuzifying so many amounts of rules, consist in apply a technique of fuzification based on functional approximation of the virtual control function by means of splitting the control function as additive sub-functions.

Looking at the table I, it can be observed that proportional gain and integral time can be associated with the cable length by functional approximation. It results in

$$Kp = fp(L) \qquad (2)$$

$$Ti = fi(L) \qquad (3)$$

The mapping from the virtual controller is

$$Yi = e.fp(L) + \Sigma e.fi(L) + \Delta e\ Td \qquad (4)$$

which is the result of adding three outputs, that is

$$Yi = Yi1 + Yi2 + Yi3 \qquad (5)$$

Consequently, the rule base is directly achieved by processing the expression 4 under a defined number of membership functions due to the properties of additive systems as follows:

e.fp(L)=

L e	100	50	25	12
-10	-40	-30	-20	-10
0	0	0	0	0
10	40	30	20	10

Σe.fi(L)=

L Σe	100	50	25	12
-20	-160	-120	80	-60
0	0	0	0	0
20	160	120	80	60

Δe Td=

L Δe	100	50	25	12
-5	-15	-15	-15	-15
0	0	0	0	0
5	15	15	15	15

The fraction of control output due to the derivative action is not length dependent, so that the fraction of rule base can be reduced to only three terms in the following manner,

Δe Td=

L Δe	any
-5	-15
0	0
5	15

Wit this method, it was possible to reduce the rule base from 108 to 27 rules based on the property of fuzzy additive functions.

For instance, for a cable length of 50 m., error = 10 m., integral of error = 20 and derivative of error –5 m/s, the additive system gives the output

Yi1 + Yi2 + Yi3 = 30+120 – 15 = 135

3. Simulation results and conclusions.

The fuzzy PID controller operates with 27 rules, where the input variables are the error, increment of error integral of error and length as shown in figure 4.

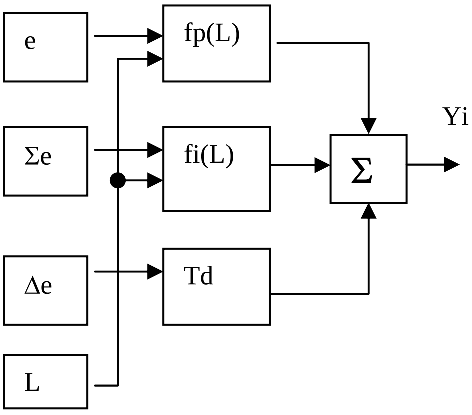

Fig. 4. The structure of resultant rule based PID controller

As shown in figure 4, the fuzzy controller comprises three rule bases in additive mode to supply a crisp output.

Cable length is an input variable to the rule base and this characteristic make de fuzzy controller operate in a similar mode as that one of the classical gain scheduling controllers

In figure 5. It is shown the time response to distance step input generated by a human operator from a crane control panel by means of a joystick. The curves (black, red and green) are respectively input command, servomotor response and load position response. As it can be observed, the response is not satisfactory at all, and it is due to the type of excitation command.

An step input command could never be applied to a position control system unless the input is being filtered. In practical applications, the input commands are gradual increasing or decreasing ramps with a limited slope.

The proposed interface helps the operator in manoeuvring to avoid excess overshoots in the transportation load task. This interface helps the human operator in avoiding paying too much attention to the load position. That is the responsibility of the human machine interface by means of the fuzzy controller algorithm.

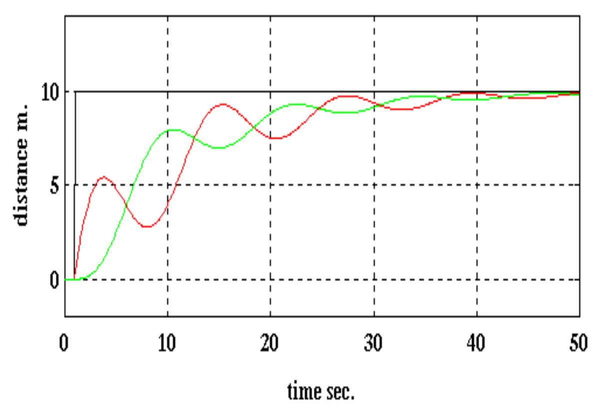

Fig. 5 Time response to a distance step input of 10 m.

In figure 6 it is shown an attempt to move a load not under a step input but a continuous ramp with varying slope. The results are illustrated by means of three curves: Black line represents the command input applied by the human operator, the red line represents the manipulated variable, that is, the actual position of the crane manipulator operated by means of a servo-system and the green line represents actual load position

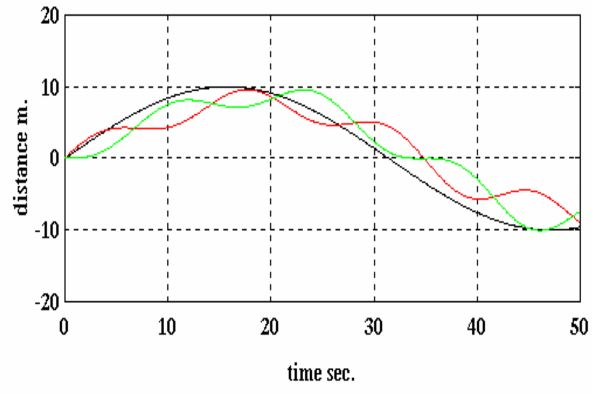

Fig. 6 Time response to a distance ramp.

In conclusion, as the objective was to follow the desired path, on the basis of achieving performance (rapid following without overshoot), by means of the use of a man-machine interface, such objective was satisfactory covered.

Consequently, the preliminary design study serves to continue on the work to complete an experimental work by an application with the possibility of improvement on control performance by properly adjusting the reduced rule base.

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