The Smart Ogy Control of Two-Link Rigid Robot Arm

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***Abstract*: The smart OGY control method is proposed for two-link rigid robot arm. For this goal the Bifurcation diagram should be applied for acceptable wide range of the input amplitude. Then by using the robot arm in a chaotic amplitude range and Poincare section, the UPO's will be found. After that, the OGY rules are defined for each UPO's and the maximum changed value of amplitude for each UPO's, which can be controlled with the computed gains, are obtained. So we have a lot of fuzzy regions a round of UPOs with the definite controlling rules. These regions should be overlapped and covered all spaces between two nearer fixed-points. By this way, the system could be controlled by routing the best path with considering the lowest consumption through the UPOs.**

Keyword: fuzzy control, OGY control, two-link rigid robot, Poincare map

I. INTRODUCTION

The complex nonlinear systems controlling is extremely significant nowadays. Since, these systems have infinite order equations, all the states of them couldn't be considered in modelling. Behaviour of the dynamical system, chaos, has applied in different fields of science such as physics, sociology, engineering, etc. Initial conditions sensitivity, is one of the important specification in chaotic systems. So, behaviour of the system could be completely changed, by varying the initial conditions, even tiny. This chaotic characteristic allows system to observing all the states of environment.

Publication activity in this field has grown tremendously during the last decade. Starting with a few papers in 1990, the number of publications in peer reviewed journals exceeded 2700 in 200, with more than half published in 1997-2000. At first, in 1890, Poincare has reported chaotic behaviour. Three approaches to control of continuous-time chaotic systems will be discussed.

The so called "non feedback control", "OGY method" and "Pyragas method". These approaches were historically the first in the field and produced the largest number of publications.

It is worth noticing that, in spite of the enormous number of published papers, very few rigorous results are so far available. Most papers are written in a "physical style" and their conclusions are justified by computer simulations rather than analytical tools. So that, many problems remain unsolved.

The idea of feed forward control (also called non feedback or open loop control) is to change the behaviour of a nonlinear system by applying a properly chosen input function. Such an approach is attractive because of its simplicity: no measurements or extra sensors are needed. It is especially advantageous for ultrafast processes. In 1990 Otte, Grebogi and Yorke introduced OGY method to control chaotic plants. This is a discrete technique which considered the small perturbations that applied in the neighbour of the desire orbit when the trajectory crosses a specific surface, such as some Poincare section.

In 1992 C Pyragas proposed the continuous OGY, that called delay feedback control. Then the OGY controller method has been improved in several papers in order to overcome some of its limitations, such as: control of high periodic and high unstable UPO, control using time delay coordinates and control using multi parameter approach based on pole placement formalism.

The OGY method has two important problems: The first problem is the time consuming and the second is sensitivity to disturbance and perturbation. Vincent proposed a two-link rigid robot arm in 1997 that has been chaotic by using periodic external input. This method is used in this article.

In 2008 a supervisory chaos control has been proposed to overcome the first problem in OGY method, to some extent. The proposed system has two layers of control, consists of supervisor and OGY. In fact, supervisor chooses the intermediates targets one by one as temporary goals for OGY controller, then when OGY stabilizes chaotic system on one of the UPOs, another goal for OGY will be picked by supervisor. This process continues until all intermediate goals have been picked by supervisor beside and trajectory reaches to the desired unstable period orbit.

In this article, a smart fuzzy chaotic structure controls the two-link robot arm by applying proper amplitude. Then the UPOs are achieved and gains, which could stabilize them, are found. In this article, the particular regions are considered for each UPO and fixed points will be selected and their OGY rules will be turned on if they would have overlap with previous chosen UPO. This new method will be helped to remain the system in a steady state.

So, the optimum routing the robot arm will be guided from start point to the end by using a smart controller. A smart controller composed of three main parts: database, router and OGY rules.

The rest of paper organized as follow: In section 2, two-link rigid robot arm equations have been discussed. In section 3, the chaotic control method and the UPO finding technique has been explained. In section 4 new method, the smart fuzzy chaotic controller has been described. The conclusion could be found in section 5.

II. ROBOT ARM MODEL

In this paper, we used two-link rigid robot arm as a plant. It has two rigid links with two revolute joints and no end-effecter. This robot arm is considered in X-Z plane and the gravity force distributed homogeneously.

The arm shape similar to quadrate and hasn't any inequality. Therefore, the mass center of this arm is placed in the middle of each arm links. The two-link robot arm model is indicated in Fig.1.

Since the gravity force is applied to the plant, the unstable poles are appeared. So the flexibility of the system will be increased. In order to find the proper model for this plant, we used Lagrangian motion equations.

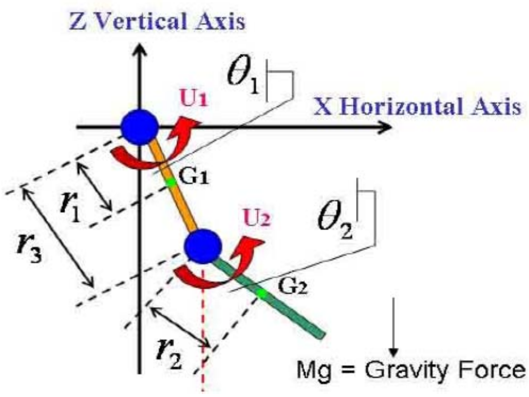

Fig.1. 2-link rigid robot arm

As seen in Fig.1 θ1 and θ2 are described first and second link angles. In order to model this plant (1), (2), (3) are used and parameters values are considered as indicated in Table1.

Table 1. List of robot arm parameters

Link number	parameters
Link1	r1 = 0.292 m , r3 = 0.413 m , I1 = 0.068 Kg m2 , R1=7.7 v/A, m1=0.602 Kg , K γ1 =0.08 Kg m2/As2 , Kβ1 = 5.2 vs2/rad
Link2	R2 = 0.198 m , I2 = 0.00474 Kg m2, m2 = 0.076 Kg , Kγ2 = 0.001 Kgm2/As2

$$(m_1 r_1^2 + m_2 r_3^2)\ddot{\theta}_1 + m_2 r_2 r_3 \cos(\theta_2 - \theta_1)\ddot{\theta}_2 - m_2 r_2 r_3 \sin(\theta_2 - \theta_1)\dot{\theta}_2 + m_1 g r_1 \operatorname{sign}\theta_1 + m_2 g r_3 \sin\theta_1 = \tau_1 - \tau_2 \quad (1)$$

$$m_2 r_2^2 \theta_2 + m_2 r_2 \cos(\theta_2 - \theta_1)\ddot{\theta}_1 + m_2 r_2 r_3 \sin(\theta_2 - \theta_1)\dot{\theta}_1^2 + m_2 g r_2 \sin\theta_2 = \tau_2 \quad (2)$$

$$\tau_1 = \frac{k_{\gamma 1}}{R_1} U_1 - \frac{k_{\gamma 1} K_{B1}}{R_1} X_2, \qquad \tau_2 = k_{\gamma 2} U_2 \quad (3)$$

Where U1 and U2 are torques of the first and second links' and defined as below:

$$U_1 = A\cos(Ft) \quad (4)$$
$$U_2 = 0 \quad (5)$$

Where, A and F are indicated as amplitude and frequency, respectively. The above terms which are as a model of the two-link robot arm have been implemented in MATLAB SIMULINK. In Fig.2, the results of modelling for 5.05, as an amplitude value, and 5, as a frequency value, described.

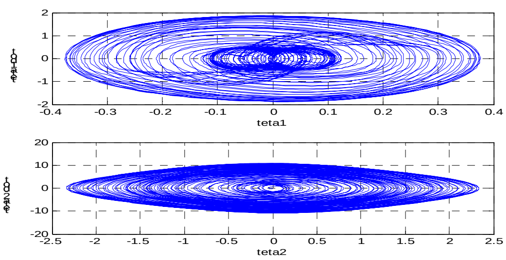

Fig.2. Result of modelling for two-link robot arm.

After the robot arm modelling is performed, we should choose the appropriate amplitude to place it in a chaotic space. There are two other useful ways to behave the plants chaotically.

These two ways are changing initial conditions and system's parameters. Since, these ways are not practical and this plant couldn't chaotic by two these ways, we didn't use them in this article.

III. CHAOTIC CONTROL

This new control method is a progressing model of OGY control, which proposed in 1990 by Otte, Grebogi and Yorke. To find the system chaotic region by varying in amplitude and frequency, we should apply the Bifurcation diagram.

A. Bifurcation

In order to apply the suitable external input which can place system in chaotic space, we used Bifurcation diagrams.

These diagrams have been plot by local maximums of two angles' trajectories consideration for both frequency and output amplitude. So, the particular region such as periodic, chaotic and unstable will be indicated.

As seen in Fig.3 and Fig.4, three regions are appeared for frequency and amplitude Bifurcation diagrams. Amplitude is equal to 5.3 in frequency Bifurcation diagram and frequency is equal to 5 in amplitude Bifurcation diagram.

Frequency Bifurcation diagram include of 3 regions as below. It has described for 2 links robot arm, separately in Fig.3.

- f ~ <4.85(rad/sec): periodic behavior.
- 4.85 ~ < f ~ < 5.4(rad/sec): chaotic behavior.
- f > ~ 5.4(rad/sec): periodic behavior.

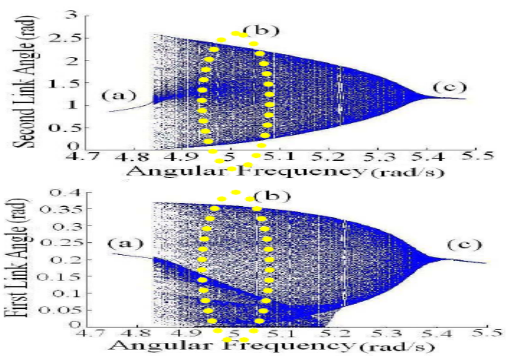

Fig.3. Frequency Bifurcation diagram for the first and second link angle.

Amplitude Bifurcation diagram composed of three regions as follow:

- A ~ < 4.25 (v): periodic behavior.
- 4.25(v) ~ < A ~ < 7(v): chaotic behavior.
- A >~ 7(v): unstable behavior.

Fig.4 showed this diagram for 2 links robot arm.

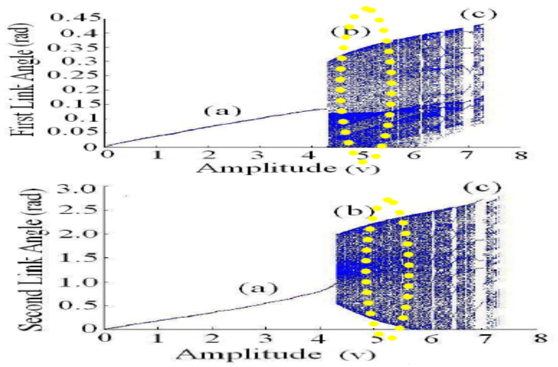

Fig.4. Amplitude Bifurcation diagram for the first and second link angle.

B. Lyapunov Exponent Diagram

Lyapunov exponent are used for defining 3 different behaviours, such as chaotic, periodic and aperiodic. In chaotic behaviour, at least one of the Lyapunov exponents should be positive and one should be negative. In addition, the summation of all exponents should be more than zero.

Definition: consider a d-dimensional system defined by a set of ordinary differential equations:

$$\frac{d}{dt}\mathbf{x}(t) = \mathbf{F}(\mathbf{x};\varphi) \qquad (6)$$

If small initial perturbation, $\varepsilon(0)=\varepsilon_0$, is applied to that, trajectory becomes y(t)=X0+ε(t). For an appropriately chosen ε_0, the exponential rate of expansion or contraction in the direction of ε_0 on the trajectory passing through X0 defines the Lyapunov exponent along that direction:

$$\lambda_i = \lim_{N\to\infty} \frac{1}{N}\sum_{k=1}^{N} \ln\left(\frac{\|\varepsilon_k\|}{\|\varepsilon_0\|}\right) \qquad (7)$$

Where ||.|| denotes the vector norm.

C. Poincare Map

Choosing the proper Poincare section is the most important point in finding Poincare map. Fixed points are located on Poincare map where intersects with bisector.

We used the plane which angular velocity of each link is zero. One of the fixed-point which have been found in 5.05 as an external input is described in (8):

$$p* = \begin{bmatrix} 0.0130 \\ 0.0077 \\ 2.0424 \\ 2.2439 \end{bmatrix} \quad (8)$$

D. The OGY Method

By using the OGY algorithm the selected UPO's will be stabilized. In addition to, amplitude of the external input has been applied to the system as control parameter.

α =ά+ δα, where δα is a small correction to the standard value of ά = 5.3. δα is adjusted at each switching point. Therefore, this task leads dependence of Poincare map of the system which we indicate it via φ:

$$p_{i+1} = \varphi\,(pi\,,\,bi) \quad (9)$$

Let p* be an UPO of Poincare map for ά = 5.3.

$$P^* = \varphi\,(\,p^*\,,\,ά\,) \quad (10)$$

For pi close to p*, and αi close to ά the Poincare map in (9) can be approximated by linear map in (10):

$$\delta p_{i+1} = A\delta p_i + B\delta\alpha_i \quad (11)$$

Where δp = pi – p* and δαi = αi – ά are the deviation from the nominal values and the system matrices are given by:

$$A = (\partial\varphi/\partial p)\,|\,(p^*\,,\,ά) \quad B = (\,\partial\varphi/\partial\alpha)\,|\,(p^*\,,\,ά) \quad (12)$$

$$\delta\alpha_i = -K\,\delta p_i \quad (13)$$

$$\delta p_{i+1} = (\,A - BK\,)\,\delta p_i \quad (14)$$

A linear state feedback is applied to the discrete time system (11). From (14) it can be seen that the closed loop system is stable as long as

$$|\,eig\,(A - BK)\,| < 1 \quad (15)$$

In order to find the best gains, that could stabilize UPO, the DLQR method is applied. This method is found in MATLAB software.

IV. A SMART FUZZY CHAOTIC CONTROLLER

As explained before, at the first step, the database should be found. So, the external amplitude which is in chaotic range (between 4.25(v) to 7(v), according to the Bifurcation diagram) applied to the system. Then, the UPOs are found by using Poincare map. It means that, the θ1 and θ2 angles value are selected, when their velocity angles are near to zero. Then the iteration map is obtained and the UPOs are placed on it where intersects with bisector. In order to specify the proper control gain to each UPO, we used OGY method. So we have a lot of fixed-points with their OGY rules.

In order to find a stabilized range, the fixed-points are changed in a very small range and applied to the system as an initial value. So, the controllable range maximum of gain for each UPO is obtained. By this way, the database, which contains the p* and its regions, will be achieved.

A. Controller structure

As appeared in Fig.5, this smart controller composed of two main parts: router and OGY rules. At the beginning, the start and the end points are defined by user. So, the controller should find the shortest path from the start to the end point through the UPOs. This process is called routing and performed by router that contains of three sections: Database, comparator and selector. Compare the start point with all UPOs to find the nearest and then compare the selected UPO with the end point, are two tasks of comparator.

The comparator communicates with Database and compares the system outputs with all UPOs. The comparator outputs will be entered to the selector unit. Then the selector unit by using the Database defines the index of selected UPOs. So, the OGY rules unit could be found the respective gain and amplitude and then applied them to the plant. This process will be continued until the end point appeared.

In order to fuzzify the OGY control, we considered some conditions and rules. These conditions are respecting to the best fixed-points selecting step. The nearest UPO to the system output will be selected but two below conditions should be overcome:

- The region of selected fixed-point has an overlap with the last selected UPO.
- The new selected fixed-points should be the nearest UPO to the end point. It means that the controller have to consider the local minimum and just selects the general minimum distance from the end point.

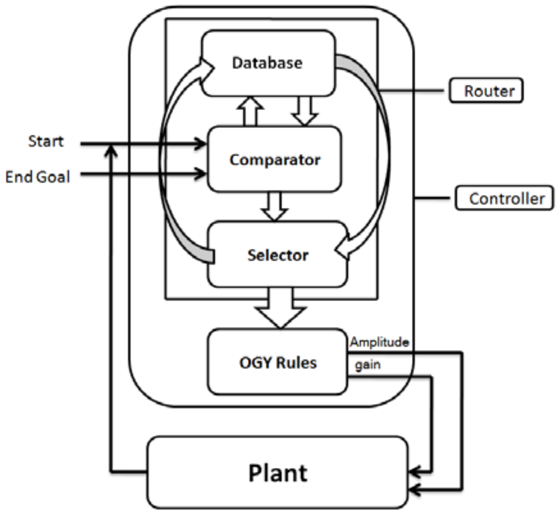

Fig.5. Controller block diagram

B. *Fuzzy rules and conditions*

As appeared in Fig.6, p1* is nearer to the start point than p2* but the selector will choose p2* because it is nearer to the end point than p1*. So, when the router chooses the best path by noticing the fuzzy rules, the amplitude and gains, are applied to the plant.

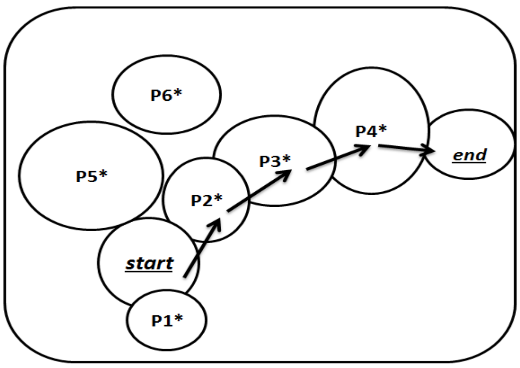

Fig.6. the UPO's selecting method.

V. CONCLUSION

In this article, we have proposed a smart controller to control the robot arm which could be chaotic by the external amplitude. Then by using Poincare map we have achieved UPOs and its' stabilize regions. Since this method is an online, the controller may be selected the local minimum points and the shortest path won't be appeared. But this method has been proposed because of time consuming. As seen in Fig.7 this controller could be found the path from start to the end.

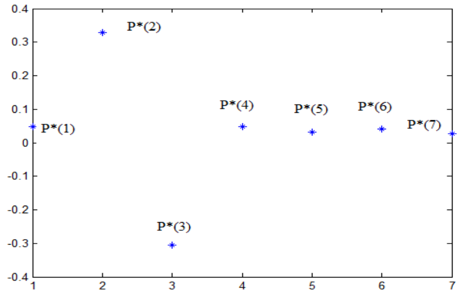

Fig.7. Routing result

P*(1) and P*(7) have been considered as the start and end point respectively. The p* values are described in Table II.

Table 2. P* RESULT

P*(1)	P*(2)	P*(3)	P*(4)	P*(5)	P*(6)	P*(7)
0.04800	0.3283	- 0.3048	0.0490	0.0310	0.0420	0.0260
-0.0051	- 0.5182	- 0.3992	0.0023	- 0.0117	0.0042	-0.001
-0.3681	0.0480	0.0470	1.6453	1.7513	1.6793	-1.126
5.2391	- 0.0366	0.0561	- 0.3634	- 0.1711	-0.271	-9.056

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