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Approach to OGY Control Fuzzification of 2-link Rigid Robot Arm with Fixed-Points Distances Considering (Using Method Similar to Bellman-Ford Algorithm)

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Abstract

In this study, an OGY control has been proposed which have been fuzzified by particular regions definition for fixed-points. In fact, we used the two-link arm of robot in chaotic space by applying the proper input. Then by using the Poincare map, the unstable period orbits (UPOs) have been obtained. At this step, we have a lot of UPOs and each of them could be controlled with the OGY rules. The controllable radius has been considered for each UPO's. So, we have a complete database which concludes of: The UPO's, the OGY rules and their controllable regions. The plant will be controlled by optimum routing via these UPOs as a point of the shortest path. These UPOs should be overlapped and covered all the spaces between two nearer fixed-points. By this way, the system could be controlled by routing the shortest path with considering the lowest consumption through the UPOs.

Keywords: OGY Control, Unstable Period Orbit (UPO), Distance Matrix, Tow-Link Rigid Robot Arm, Bifurcation Diagram, Bellman-Ford algorithm

1. 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 modeling. Behavior 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, behavior of the system could be completely changed, by varying in initial conditions, even shortly. This chaotic characteristic allows system to observing all the states of environment.

In 1990 Otte, Grebogi and Yorke introduced OGY method to control chaotic plants [1],[12]. This is a discrete technique that considered the small perturbations that applied in the neighbor of the desire orbit when the trajectory crosses a specific surface, such as some Poincare section [2],[3]. Pyragas proposed the continuous OGY, that called delay feedback control [4]. 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 [5],[6],[7], control using time delay coordinates [8],[9],[10] and control using multi parameter approach based on pole placement formalism [11].

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 [12],[13]. This method is used in this article.

In [12] 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, an intelligent 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. So, the optimum routing the robot arm will be guided from an initial point to the end by using an intelligent controller.

An intelligent controller composed of three main parts: database, router and OGY rules.

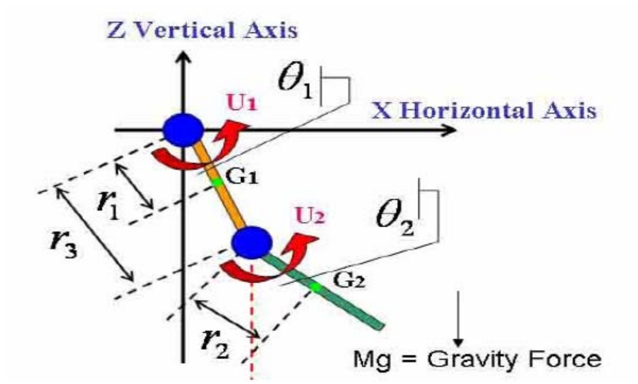
The rest of paper organized as follow: In section 2, two-link rigid robot arm equations have been discussed. In section 3, the chaotic control method and the UPO finding technique has been explained. In section 4, new method, fuzzy chaotic controller has been described. The conclusion could be found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

2. 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 tow-link robot arm model is indicated in Figure 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.

Figure 1: Two-link rigid robot arm



As seen in Fig.1 θ_1 and θ_2 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

$$\begin{aligned}(m_1 r_1{}^2 + m_2 r_3{}^2)\ddot{\theta}_1 + m_2 r_2 r_3 \cos(\theta_2 - \theta_1)\,\ddot{\theta}_2 - m_2 r_2 r_3 \sin(\theta_2 - \theta_1)\,\dot{\theta}_2 \\ + m_1 g r_1 \,\mathrm{sign}\,\theta_1 + m_2 g r_3 \sin\theta_1 = \tau_1 - \tau_2\end{aligned} \tag{1}$$

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

$$\begin{aligned}\tau_1 &= \frac{k_{\gamma 1}}{R_1} U_1 - \frac{k_{\gamma 1} K_{B1}}{R_1} X_2 \\ \tau_2 &= k_{\gamma 2} U_2\end{aligned} \tag{3}$$

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

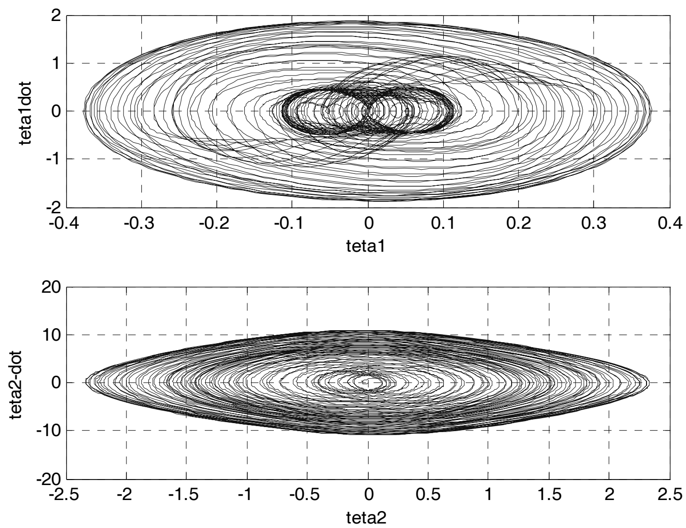
$U_1 = A \cos(Ft)$ (4)

$U_2 = 0$ (5)

Where, A and F are indicated as amplitude and frequency, respectively.

In Figure 2, the results of modeling for 5.05, as an amplitude value, and 5, as a frequency value, are described.

Figure 2: Modeling result for tow-link robot arm.



After the robot arm modeling 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 [12].

3. 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 map.

3.1. Bifurcation

In order to apply the suitable external input which can place system in chaotic space, we used bifurcation diagram for frequency and amplitude. So, the particular region such as periodic, chaotic and unstable will be indicated.

As written in [12], 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.

f ~ <4.85(rad/sec): periodic behavior.

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

f > ~ 5.4(rad/sec): periodic behavior.

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.

3.2. 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. As written in [12], 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 (6):

$$p^* = \begin{bmatrix} 0.0130 \\ 0.0077 \\ 2.0424 \\ 2.2439 \end{bmatrix} \quad (6)$$

3.3. The OGY Method

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

$\alpha = \acute{\alpha} + \delta\alpha$, where $\delta\alpha$ is a small correction to the standard value of $\acute{\alpha} = 5.3$. $\delta\alpha$ is adjusted at each switching point. Therefore, this task leads dependence of Poincare map of the system which we indicate it via φ:

$$p_{i+1} = \varphi(p_i, b_i) \quad (7)$$

Let p* be an UPO of Poincare map for $\acute{\alpha} = 5.3$.

$$P^* = \varphi(p^*, \acute{\alpha}) \quad (8)$$

For p_i close to p*, and α_i close to $\acute{\alpha}$ the Poincare map in (7) can be approximated by linear map in (8):

$$\delta p_{i+1} = A\delta p_i + B\delta\alpha_i \quad (9)$$

Where $\delta p = p_i - p^*$ and $\delta\alpha_i = \alpha_i - \acute{\alpha}$ are the deviation from the nominal values and the system matrices are given by

$$A = (\partial\varphi/\partial p) \mid (p^*, \acute{\alpha}) \; B = (\partial\varphi/\partial\alpha) \mid (p^*, \acute{\alpha}) \quad (10)$$

$$\delta\alpha_i = -K\, \delta p_i \quad (11)$$

$$\delta p_{i+1} = (A - BK)\, \delta p_i \quad (12)$$

A linear state feedback is applied to the discrete time system (9). From (12) it can be seen that the closed loop system is stable as long as

$$\mid eig\,(A - BK) \mid < 1 \quad (13)$$

In order to find the best gains, that could stabilize UPO, the DLQR method is applied [12],[15].

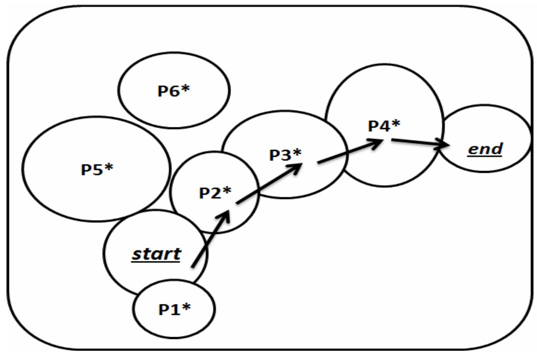
4. Controller Structure

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 θ_1 and θ_2 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 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 will be obtained.

By this way, the database, which contains the p*'s, their controllable regions and the controlling gains will be achieved. In the other words, the UPO's (corresponding to the input amplitude), has been fuzzified and the OGY control rules has been considered for them. Therefore when we want to change the UPO's from point to another point, we should change the input amplitude. But if we change the amplitude suddenly, the system will be in an instability state. In fact, the proper UPO's will be selected by changing the amplitude if they have overlap with the others. The UPO's that are linked to the other because of their regions create a path which is similar to a rope. The schematic is shown in Figure 3. Thus, the routing process should be started, at the second step, to define the optimum path.

Figure 3: The selected UPOs like rope.



A controller structure will be carried out in offline and online states. In order to find the optimum path, a method has been used that similar to Bellman-Ford algorithm and will be performed in an offline state. This algorithm concludes of two parts: "Distance" matrix achievement and routing.

At first, "Distance" matrix should be created that includes of the UPO's distances. It is a square matrix and its size is corresponding to the UPO's numbers and defined as below:

"Infinite" value has been considered for the two UPO's that haven’t overlapped with others.

"Real distance" value (by using Oghlidos distance) has been considered between two UPO's that have overlapped.

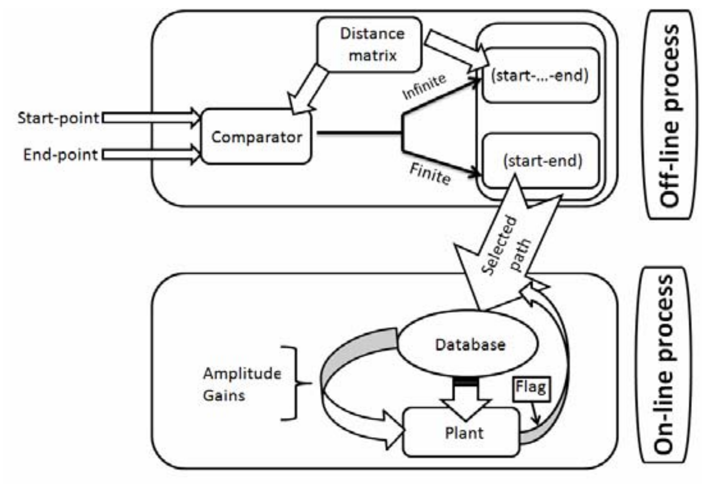
"Zero" value has been considered for arrays that are placed in matrix main diagonal.

Then, at the second step, the routing algorithm should be started. In Figure 4 the block diagram of this controller has been shown. The process steps are explained as below:

1. The start and end points are defined by user.
2. UPO's distances are obtained according to the "Distance" matrix.
3. If the UPO's distance is equal to "finite" value: this value is considered as the shortest energy of path. It means that, the selecting path is: (start-end).
4. If the UPO's distance is equal to "infinite" value: By this way the algorithm should be found the interface UPO's, to define the shortest path. (May be isn’t any path from the start point to the end).

This algorithm has different from Bellman-Ford algorithm such as the values in Distance matrix are not updated and modified during the time. So, the optimum path will be obtained by the proposed algorithm. It’s the end of an offline process and the online process step will be started. As we discussed before, the OGY control method is done by applying the specified amplitude and controlling gains. So, points of the path are selected one by one, and their OGY rules are applied to the plant as a result of the database. When the OGY rules of one point applied to the plant essentially, Flag (as seen in Figure 4) will be changed and another point of the path will e selected.

Figure 4: The controller block diagram



5. Conclusion

In this article, we have proposed a 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 and by optimum routing the plant could be controlled and the desire end points will be obtained.

Then by using the algorithm which is similar to Bellman-Ford algorithm, the controlling process has been performed.

For example, if the start point number is equal to 10 and the end point number equal number to 598 the selected path will be found as below:

[10 101 598] (14)

These are the number of UPO's that illustrate the three UPO's as TABLE I:

Table I: p* result

P*(10)	**P*(101)**	**P*(598)**
0.0060000000000000	0.0120000000000000	0.0380000000000000
-0.009165440400800	-0.016669744241205	-0.015401335486355
-1.138266640421591	-0.752386006362443	0.883473220323851
6.596337001898002	8.144750928473492	8.08292580036867

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