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Method of Matrices Operations in H2 Control for Calcium Ion Channel on the Biological Membrane as a Closed Circuit.

H, Hirayama, *Y. Okita., *T, Sugiura,
*M, Kimura and **T. Kazui
Department of Public Health Asahikawa medical college.
E mail , hirayama@asahikawa-med.ac.jp
*Shizuoka university. **Hamamatsu medical college.

あらまし　I have proposed an h2 control principle for bio chemical noise filtering function of the calcium in channel on the excitable cellular membrane. The Calcium channel is composed of four identical subunits. Each of which contains a helical segment which contains a lot of electrical charge that acts as a membrane voltage sensor. The opening and closing of the channel pore are facilitated by the activating positionings of the voltage sensor. The temporal changes i the system were described by ten differential equations under the condition that minimizes the 2 norm of the transfer function of the system from the noise input the out put. The computed temporal changes in the open and closed states are significantly influenced by the changes in the amounts of the control inputs. The present methods, when extended will be available for evaluating the filtering function of the bio membranes.

和文キーワード　Bio membrane, calcium in, Channel, Subunits, Voltage sensor, H2 control, Noise, 2 norm.

閉回路としてのカルシウムイオンチャンネルのH２制御

平山博史、*沖田善光、*杉浦敏文、*木村元彦、**数井輝久

旭川医科大学、旭川市緑が丘東２条１丁目
*静岡大学.　**浜松医科大学

Abstract

カルシウムイオンを選択的に通過させるカルシウムイオンチャンネルの機能特性を雑音フィルターの視点からＨ２制御を用いて解析する方法を提唱した。カルシウムイオンチャンネルは４個の相同性の高いサブユニットから構成されている。また膜電位感受性を有するタンパク分子がそれぞれのサブユニットに付属し、その空間内の位置が変化することでチャンネル開閉が加速される。本研究では１０個のチャンネル構造を１０個の状態方程式で表示し、雑音が出力されるまでの系の伝達関数の２ノルムを最少にする場合のチャンネルの状態の過渡的状況を数値計算で決定した。制御入力の変化によって開状態、閉状態のチャンネルの時間経過を大きく影響された。　本研究を発展させることで生体膜チャンネルの生化学的雑音低減効果を評価できる可能性を示唆した。

英文 key words　生体膜.　カルシウムイオン.　チャンネル.　Ｈ２制御.　雑音.　伝達関数　　２ノルム

1. Introduction.

Calcium channel (Fig 1) on the excitable membrane filters only Calcium ion though there are a lot of agonist and antagonist that compete the channel with Calcium ion. Hence, the mechanism can be described by the H2 control principle. The dynamical action of the Calcium channel is characterized by four identical subunits (Fig 2) that act concertedly. The channel opening and closing are strongly influenced by a particular segment named S4 (Fig 3) which has a high voltage sensing property in each subunits. S4 contains a lot of charges on its surface. When it takes the activating position in the subunit, the transitions among the open states are facilitated. By the spatial consideration of the activating positionings of the voltage sensor, we have ten conformations of one Calcium channel. (Fig 4-a and Fig 4-b).

In the present work, we present a detailed matrix expansion for computing the H2 controlled temporal change of the amounts of the Calcium channel states.

2. Mathematical method.

The state equations for these ten conformation states are given by linear combination of weighted control inputs.

Fig 1

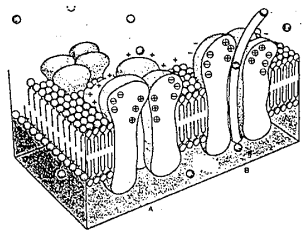


Fig 2

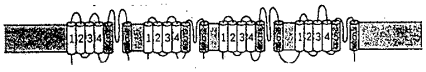


Fig 3

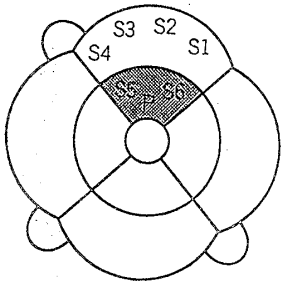
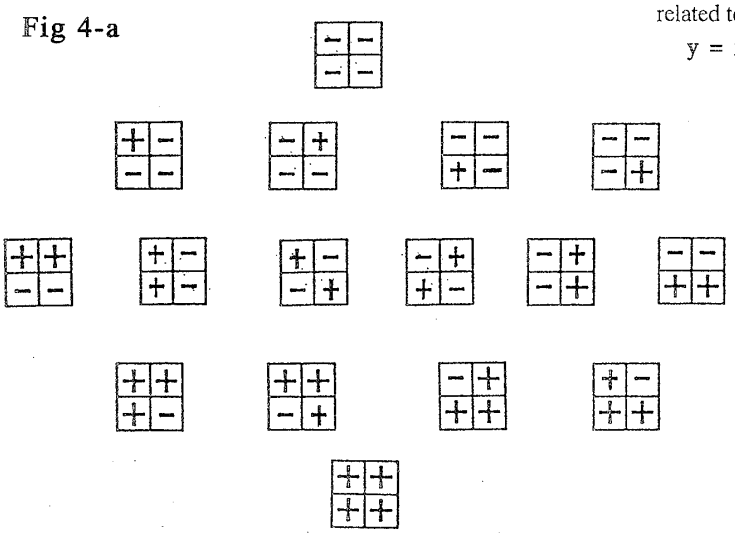


Fig 4-a



$$\partial C_0/\partial t = k\text{-}c\, C_1 + k\text{-}L / f_4\, O_0 - (4\,kc + k_L f_4)\, C_0 + p_9' u_3 + p_1' u_1 \quad \text{----------(1)}$$

$$\partial C_1/\partial t = 4\,kc\, C_0 + 2\,k\text{-}c\, C_2 + k\text{-}L / f_3\, O_1 - (k\text{-}c + 3\,kc + k_L f_3)\, C_1 + p_1 u_1 + p_{10}' u_3 + p_2' u_1 \quad \text{----------(2)}$$

$$\partial C_2/\partial t = 3\,kc\, C_1 + 3\,k\text{-}c\, C_3 + k\text{-}L / f_2\, O_2 - (2\,k\text{-}c + 2\,kc + k_L f_2)\, C_2 + p_2 u_1 + p_{11}' u_3 + p_3' u_1 \quad \text{----------(3)}$$

$$\partial C_3/\partial t = 2kc\, C_2 + 4\,k\text{-}c\, C_4 + k\text{-}L / f\, O_3 - (3\,k\text{-}c + kc + k_L f)\, C_3 + p_3 u_1 + p_{12}' u_3 + p_4' u_1 \quad \text{----------(4)}$$

$$\partial C_4/\partial t = kc\, C_3 + k\text{-}L\, O_4 - (4\,k\text{-}c + k_L)\, C_4 + p_4 u_1 + p_{13}' u_3 \quad \text{----------(5)}$$

$$\partial O_0/\partial t = f_4 k_L\, C_0 + k\text{-}c\, f\, O_1 - (k\text{-}L / f_4 + 4\,kc / f)\, O_0 + p_9 u_3 + p_5' u_2 \quad \text{---------(6)}$$

$$\partial O_1/\partial t = 4\,kc / f\, O_0 + k_L f_3\, C_1 + 2\,k\text{-}c\, f_2\, O_2 - (k\text{-}c\, f + k\text{-}L / f_3 + 3\,kc / f_2)\, O_1 + p_{10} u_3 + p_6' u_2 \quad \text{–(7)}$$

$$\partial O_2/\partial t = 3\,kc / f_2\, O_1 + k_L\, f_2\, C_2 + 3\,k\text{-}c\, f_3\, O_3 - (2\, f_2\, k\text{-}c + k\text{-}L / f_2 + 2\,kc / f_3)\, O_2 + p_{11} u_3 + p_7' u_2 \quad \text{-(8)}$$

$$\partial O_3/\partial t = 2\,kc / f_3\, O_2 + k_L\, f\, C_3 + 4\,k\text{-}c\, f_4\, O_4 - (3\,k\text{-}c\, f_3 + k\text{-}L / f + kc / f_4)\, O_3 + p_7 u_2 + p_{12} u_3 + p_8' u_2 \quad \text{-----(9)}$$

$$\partial O_4/\partial t = kc / f_4\, O_3 + k_L\, C_4 - (4\,k\text{-}c\, f_4 + k\text{-}L)\, O_4 + p_8 u_2 + p_{13} u_3 \quad \text{-----(10)}$$

The vector form

$$\partial x'(t)/\partial t = \mathbf{A}\, x + \mathbf{B1}\, w + \mathbf{B2}\, u$$

Vector form of the equation for the estimator **Z**

$$Z = \mathbf{C1}\, x + \mathbf{D12}\, u$$

Vector form of the equation for the observer out put **y**

$$y = \mathbf{C2}\, x + \mathbf{D21}\, w$$

The vector for of the optimized control u^ is given by the product of B_2, X and x^

$$u^{\wedge} = - B2T\, X\, x^{\wedge}$$

where x^ is the state vector of the observers and T denotes transpose.

$$x^{\wedge}T = [\, X_{10},\ X_{11},\ X_{12},\ X_{13},\ X_{14},\ X_{15},\ X_{16},\ X_{17},\ X_{18}\,]\, T$$

which correspond to state variables. **X** is the solution of related algebraic Riccati equation.

$$AT\, X + X\, A - X\, B2\, B2T\, X + C1T\, C1 = 0$$

The vector equation of observer x^ is given by

$$\partial x^{\wedge} / \partial t = A\, x^{\wedge} + B2\, u + Y\, C2T\, (y - C2\, x^{\wedge})$$

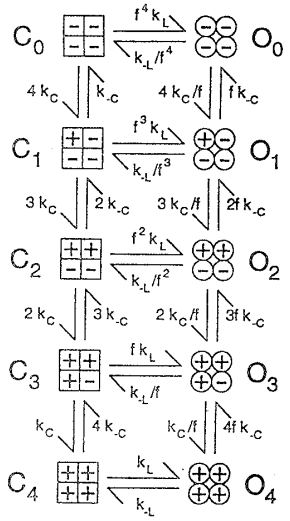
where **Y** is the solution of adjoint algebraic Riccati equation

$$A\, Y + Y\, A\, T - Y\, C2\, T\, C2\, Y + B1\, B1\, T = 0$$

To close the feed back loop of the system, y can be related to state variable x by

$$y = xd - C2\, x$$

Fig 4-b



A = [

a11	a12	a13	a14	a15	a16	a17	a18	a19
a21	0	a23	0	0	0	0	0	a29
0	a32	0	a34	0	0	0	a38	0
0	0	a43	0	a45	0	a47	0	0
0	0	0	a54	0	a56	0	0	0
0	0	0	0	a65	0	a67	0	0
0	0	0	a74	0	a76	0	a78	0
0	0	a83	0	0	0	a87	0	a89
a91	a92	a93	a94	a95	a96	a97	a98	a99];

----------%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

B_2^T =

0	0	0	0	0	b11	b13	b15	b17
b1	b3	b5	b7	b9	0	0	0	0
b2	b4	b6	b8	b10	b12	b14	b16	b18

Matrix form of the Riccati solution X is

X=

X11	X12	X13	X14	X15	X16	X17	X18	X19
X12	X22	X23	X24	X25	X26	X27	X28	X29
X13	X23	X33	X34	X35	X36	X37	X38	X39
X14	X24	X34	X44	X45	X46	X47	X48	X49
X15	X25	X35	X45	X55	X56	X57	X58	X59
X16	X26	X36	X46	X56	X66	X67	X68	X69
X17	X27	X37	X47	X57	X67	X77	X78	X79
X18	X28	X38	X48	X58	X68	X78	X88	X89
X19	X29	X39	X49	X59	X69	X79	X89	X99

The control input is

u^ = - B_2^T X x^

B_2^T X =

[X11 X12 X13 X14 X15 X16 X17 X18 X19]

0	0	0	0	0	b11	b13	b15	b17
b1	b3	b5	b7	b9	0	0	0	0
b2	b4	b6	b8	b10	b12	b14	b16	b18

=

b11 X16+ b13 X17+ b15X18 + b17 X19 : Xb11

b1 X11 + b3 X12 + b5 X13 + b7 X14 + b9X15 : Xb21

b2 X11 + b4 X12 + b6 X13 + b8 X14 + b10 X15 +

+ b12 X16 + b14 X17 + b16 X18 + b18 X19 : Xb31

[X12 X22 X23 X24 X25 X26 X27 X28 X29

0	0	0	0	0	b11	b13	b15	b17
b1	b3	b5	b7	b9	0	0	0	0
b2	b4	b6	b8	b10	b12	b14	b16	b18

=

b11 X36+ b13 X37+ b15X38 + b17 X39 : Xb13

b1 X13 + b3 X23 + b5 X33 + b7 X34 + b9X35 : Xb23

b2 X13 + b4 X23 + b6 X33 + b8 X34 + b10 X35

+ b12 X36 + b14 X37 + b16 X38 + b18 X39 : Xb33

[X14 X24 X34 X44 X45 X46 X47 X48 X49

0	0	0	0	0	b11	b13	b15	b17
b1	b3	b5	b7	b9	0	0	0	0
b2	b4	b6	b8	b10	b12	b14	b16	b18

=

b11 X46+ b13 X47+ b15X48 + b17 X49 : Xb14

b1 X14 + b3 X24 + b5 X34 + b7 X44 + b9X45 : Xb24

b2 X14 + b4 X24 + b6 X34 + b8 X44 + b10 X45

+ b12 X46 + b14 X47 + b16 X48 + b18 X49 : Xb34

[X15 X25 X35 X45 X55 X56 X57 X58 X59

0	0	0	0	0	b11	b13	b15	b17
b1	b3	b5	b7	b9	0	0	0	0
b2	b4	b6	b8	b10	b12	b14	b16	b18

=

b11 X56+ b13 X57+ b15X58 + b17 X59 : Xb15

b1 X15 + b3 X25 + b5 X35 + b7 X45 + b9X55 : Xb25

b2 X15 + b4 X25 + b6 X35 + b8 X45 + b10 X55

+ b12 X56 + b14 X57 + b16 X58 + b18 X59 : Xb35

[X16 X26 X36 X46 X56 X66 X67 X68 X69

0	0	0	0	0	b11	b13	b15	b17
b1	b3	b5	b7	b9	0	0	0	0
b2	b4	b6	b8	b10	b12	b14	b16	b18

=

b11 X66+ b13 X67+ b15X68 + b17 X69 : Xb16

b1 X16 + b3 X26 + b5 X36 + b7 X46 + b9X56 : Xb26

b2 X16 + b4 X26 + b6 X36 + b8 X46 + b10 X56

+ b12 X66 + b14 X67 + b16 X68 + b18 X69 : Xb36

[X17 X27 X37 X47 X57 X67 X77 X78 X79

0	0	0	0	0	b11	b13	b15	b17
b1	b3	b5	b7	b9	0	0	0	0
b2	b4	b6	b8	b10	b12	b14	b16	b18

=

b11 X67+ b13 X77+ b15X78 + b17 X79 : Xb17

b1 X17 + b3 X27 + b5 X37 + b7 X47 + b9X57 : Xb27

b2 X17 + b4 X27 + b6 X37 + b8 X47 + b10 X57

+ b12 X67 + b14 X77 + b16 X78 + b18 X79 : Xb37

[X19 X29 X39 X49 X59 X69 X79 X89 X99
0 0 0 0 0 b11 b13 b15 b17
b1 b3 b5 b7 b9 0 0 0 0
b2 b4 b6 b8 b10 b12 b14 b16 b18

=

b11 X69+ b13 X79+ b15X89 + b17 X99 : Xb19

b1 X19 + b3 X29 + b5 X39 + b7 X49 + b9X59 : Xb29

b2 X19 + b4 X29 + b6 X39 + b8 X49 + b10 X59
+ b12 X69 + b14 X79 + b16 X89 + b18 X99 : Xb39

Them,we have

$u = - B_2^T X x^$

=

[Xb11 Xb12 Xb13 Xb14 Xb15 Xb16 Xb17 Xb18 Xb19
Xb21 Xb22 Xb23 Xb24 Xb25 Xb26 Xb27 Xb28 Xb29
Xb31 X32 Xb33 Xb34 Xb35 Xb36 Xb37 Xb38 Xb39]

$[x10\ x11\ x12\ x13\ x14\ x15\ x16\ x17\ x18\ ]^T$

=

- [Xb11X10 + Xb12 X11 + Xb13 X12 + Xb14 X13+ Xb15 X14+ Xb16 X15+ Xb17 X16 + Xb18 X17 + Xb19 X18

Xb21 X10 + Xb22 X11 + Xb23 X12 + Xb24 X13+ Xb25 X14 + Xb26 X15+ Xb27 X16 + Xb28 X17 + Xb29 X18

Xb31 X10 + Xb32 X11 + Xb33 X12+ Xb34 X13+ Xb35 X14 + Xb36 X15 + Xb37 X16 + Xb38 X17 + Xb39 X18]

$$B2 \begin{bmatrix} 0 & b1 & b2 \\ 0 & b3 & b4 \\ 0 & b5 & b6 \\ 0 & b7 & b8 \\ 0 & b9 & b10 \\ b11 & 0 & b12 \\ b13 & 0 & b14 \\ b15 & 0 & b16 \\ b17 & 0 & b18 \end{bmatrix}$$

B2 u =

b1 (Xb21 X10 +Xb22 X11+Xb23 X12 + Xb24 X13+ Xb25 X14 + Xb26 X15+ Xb27 X16 + Xb28 X17 + Xb29 X18)
+ b2(Xb31 X10 + Xb32 X11 + Xb33 X12+ Xb34 X13+ Xb35 X14 + Xb36 X15 + Xb37 X16 + Xb38 X17 + Xb39 X18)

b3 (Xb21 X10 +Xb22 X11+Xb23 X12 + Xb24 X13+ Xb25 X14 + Xb26 X15+ Xb27 X16 + Xb28 X17 + Xb29 X18)
+ b4(Xb31 X10 + Xb32 X11 + Xb33 X12+ Xb34 X13+ Xb35 X14 + Xb36 X15 + Xb37 X16 + Xb38 X17 + Xb39 X18)

b5 (Xb21 X10 +Xb22 X11+Xb23 X12 + Xb24 X13+ Xb25 X14 + Xb26 X15+ Xb27 X16 + Xb28 X17 + Xb29 X18)
+ b6(Xb31 X10 + Xb32 X11 + Xb33 X12+ Xb34 X13+ Xb35 X14 + Xb36 X15 + Xb37 X16 + Xb38 X17 + Xb39 X18)

b7 (Xb21 X10 +Xb22 X11+Xb23 X12 + Xb24 X13+ Xb25 X14 + Xb26 X15+ Xb27 X16 + Xb28 X17 + Xb29 X18)
+ b8(Xb31 X10 + Xb32 X11 + Xb33 X12+ Xb34 X13+ Xb35 X14 + Xb36 X15 + Xb37 X16 + Xb38 X17 + Xb39 X18)

b9 (Xb21 X10 +Xb22 X11+Xb23 X12 + Xb24 X13+ Xb25 X14 + Xb26 X15+ Xb27 X16 + Xb28 X17 + Xb29 X18)
+ b10(Xb31 X10 + Xb32 X11 + Xb33 X12+ Xb34 X13+ Xb35 X14 + Xb36 X15 + Xb37 X16 + Xb38 X17 + Xb39 X18)

b11(Xb11X10 + Xb12 X11 + Xb13 X12 + Xb14 X13+ Xb15 X14+ Xb16 X15+ Xb17 X16 + Xb18 X17 + Xb19 X18
+ b12 (Xb31 X10 + Xb32 X11 + Xb33 X12+ Xb34 X13+ Xb35 X14 + Xb36 X15 + Xb37 X16 + Xb38 X17 + Xb39 X18

b13(Xb11X10 + Xb12 X11 + Xb13 X12 + Xb14 X13+ Xb15 X14+ Xb16 X15+ Xb17 X16 + Xb18 X17 + Xb19 X18
+ b14 (Xb31 X10 + Xb32 X11 + Xb33 X12+ Xb34 X13+ Xb35 X14 + Xb36 X15 + Xb37 X16 + Xb38 X17 + Xb39 X18

b15(Xb11X10 + Xb12 X11 + Xb13 X12 + Xb14 X13+ Xb15 X14+ Xb16 X15+ Xb17 X16 + Xb18 X17 + Xb19 X18
+ b16 (Xb31 X10 + Xb32 X11 + Xb33 X12+ Xb34 X13+ Xb35 X14 + Xb36 X15 + Xb37 X16 + Xb38 X17 + Xb39 X18

b17(Xb11X10 + Xb12 X11 + Xb13 X12 + Xb14 X13+ Xb15 X14+ Xb16 X15+ Xb17 X16 + Xb18 X17 + Xb19 X18
+ b18 (Xb31 X10 + Xb32 X11 + Xb33 X12+ Xb34 X13+ Xb35 X14 + Xb36 X15 + Xb37 X16 + Xb38 X17 + Xb39 X18

setting
****

b1 Xb21 + b2 Xb31 = Xa1,
b1 Xb22 + b2 Xb32 = Xa2,
b1 Xb23 + b2 Xb33 = Xa3,
b1 Xb24 + b2 Xb34 = Xa4,
b1 Xb25 + b2 Xb35 = Xa5,
b1 Xb26 + b2 Xb36 = Xa6,
b1 Xb27 + b2 Xb37 = Xa7
b1 Xb28 + b2 Xb38 = Xa8
b1 Xb29 + b2 Xb39 = Xa9

b3 Xb21 + b4 Xb31 = Xa10,
b3 Xb22 + b4 Xb32 = Xa11,
b3 Xb23 + b4 Xb33 = Xa12,
b3 Xb24 + b4 Xb34 = Xa13,
b3 Xb25 + b4 Xb35 = Xa14,
b3 Xb26 + b4 Xb36 = Xa15,
b3 Xb27 + b4 Xb37 = Xa16
b3 Xb28 + b4 Xb38 = Xa17
b3 Xb29 + b4 Xb39 = Xa18

b5 Xb21 + b6 Xb31 = Xa19,
b5 Xb22 + b6 Xb32 = Xa20,
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b5 Xb24 + b6 Xb34 = Xa22,
b5 Xb25 + b6 Xb35 = Xa23,
b5 Xb26 + b6 Xb36 = Xa24,
b5 Xb27 + b6 Xb37 = Xa25
b5 Xb28 + b6 Xb38 = Xa26
b5 Xb29 + b6 Xb39 = Xa27

b9 Xb21 + b10 Xb31 = Xa37,
b9 Xb22 + b10 Xb32 = Xa38,
b9 Xb23 + b10 Xb33 = Xa39,
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b17 Xb18 + b18 Xb38 = Xa80
b17 Xb19 + b18 Xb39 = Xa81

B2 u =

Xa1 X10 + Xa2 X11 + Xa3 X12 + Xa4 X13 + Xa5 X14 + Xa6 X15 + Xa7 X16 + Xa8 X17 + Xa9 X18

Xa10 X10 + Xa11 X11 + Xa12 X12 + Xa13 X13 + Xa14 X14 + Xa15 X15 + Xa16 X16 + Xa17 X17 + Xa18 X18

Xa19 X10 + Xa20 X11 + Xa21 X12 + Xa22 X13 + Xa23 X14 + Xa24 X15 + Xa25 X16 + Xa26 X 17 + Xa27 X18

Xa28 X10 + Xa29 X11 + Xa30 X12 + Xa31 X13 + Xa32 X14 + Xa33 X15 + Xa34 X16 + Xa35 X17 + Xa36 X18

Xa37 X10 + Xa38 X11 + Xa39 X12 + Xa40 X13 + Xa41 X14 + Xa42 X15 + Xa43 X16 + Xa44 X17 + Xa45 X18

Xa46 X10 + Xa47 X11 + Xa48 X12 + Xa49 X13 + Xa50 X14 + Xa51 X15 + Xa52 X16 + Xa53 X17 + Xa54 X18

Xa55 X10 + Xa56 X11 + Xa57 X12 + Xa58 X13 + Xa59 X14 + Xa60 X15 + Xa61 X16 + Xa62 X17 + Xa63 X18

Xa64 X10 + Xa65 X11 + Xa66 X12 + Xa67 X13 + Xa68 X14 + Xa69 X15 + Xa70 X16 + Xa71 X17 + Xa72 X18

Xa73 X10 + Xa74 X11 + Xa75 X12 + Xa76 X13 + Xa77 X14 + Xa78 X15 + Xa79 X16 + Xa80 X17 + Xa81 X18

***Observe 9 states ---

C2t (y - C2 X(10-18*)=

C2 = [1 0 0 0 0 0 0 0 0 y1 - 1 0 0 0 0 0 0 0 0 x10
0 1 0 0 0 0 0 0 0 y2 - 0 1 0 0 0 0 0 0 0 x11
0 0 1 0 0 0 0 0 0 y3 - 0 0 1 0 0 0 0 0 0 x12
0 0 0 1 0 0 0 0 0 y4 - 0 0 0 1 0 0 0 0 0 x13
0 0 0 1 0 0 0 0 0 y5 - 0 0 0 1 0 0 0 0 0 x14
0 0 0 0 0 1 0 0 0 y6 - 0 0 0 0 0 1 0 0 0 x15
0 0 0 0 0 0 1 0 0 y7 - 0 0 0 0 0 0 1 0 0 x16
0 0 0 0 0 0 0 1 0 y8 - 0 0 0 0 0 0 0 1 0 x17
0 0 0 0 0 0 0 0 1] y9 - 0 0 0 0 0 0 0 0 1 x18

C2 = [1 0 0 0 0 0 0 0 0 y1 - x10 = y1 - x10
0 1 0 0 0 0 0 0 0 y2 - x11 y2 - x11
0 0 1 0 0 0 0 0 0 y3 - x12 y3 - x12
0 0 0 1 0 0 0 0 0 y4 - x13 y4 - x13
0 0 0 1 0 0 0 0 0 y5 - x14 y5 - x14
0 0 0 0 0 1 0 0 0 y6 - x15 y6 - x15
0 0 0 0 0 0 1 0 0 y7 - x16 y7 - x16
0 0 0 0 0 0 0 1 0 y8 - x17 y8 - x17
0 0 0 0 0 0 0 0 1] y9 - x18 y9 - x18

Y(9,9) C2T (y - C2 X(10-18*)

Y11 Y12 Y13 Y14 Y15 Y16 Y17 Y18 Y19 y1 - x10
Y12 Y22 Y23 Y24 Y25 Y26 Y27 Y28 Y29 y2 - x11
Y13 Y23 Y33 Y34 Y35 Y36 Y37 Y38 Y39 y3 - x12
= Y14 Y24 Y34 Y44 Y45 Y46 Y47 Y48 Y49 y4 - x13
Y15 Y25 Y35 Y45 Y55 Y56 Y57 Y58 Y59 y5 - x14
Y16 Y26 Y36 Y46 Y56 Y66 Y67 Y68 Y69 y6 - x15
Y17 Y27 Y37 Y47 Y57 Y67 Y77 Y78 Y79 y7 - x16
Y18 Y28 Y38 Y48 Y58 Y68 Y78 Y88 Y89 y8 - x17
Y19 Y29 Y39 Y49 Y59 Y69 Y79 Y89 Y99 y9 - x18

=

Y11(y1 -x10)+Y12(y2 - x11)+Y13(y3 - x12)+Y14(y4 - x13)+Y15(y5 - x14)+Y16(y6 - x15)+Y17(y7 - x16)+Y18(y8 - x17)
Y12(y1 -x10)+Y22(y2 - x11)+Y23(y3 - x12)+Y24(y4 - x13)+Y25(y5 - x14)+Y26(y6 - x15)+Y27(y7 - x16)+Y28(y8 - x17)
Y13(y1 -x10)+Y23(y2 - x11)+Y33(y3 - x12)+Y34(y4 - x13)+Y35(y5 - x14)+Y36(y6 - x15)+Y37(y7 - x16)+Y38(y8 - x17)
Y14(y1 -x10)+Y24(y2 - x11)+Y34(y3 - x12)+Y44(y4 - x13)+Y45(y5 - x14)+Y46(y6 - x15)+Y47(y7 - x16)+Y48(y8 - x17)
Y15(y1 -x10)+Y25(y2 - x11)+Y35(y3 - x12)+Y45(y4 - x13)+Y55(y5 - x14)+Y56(y6 - x15)+Y57(y7 - x16)+Y58(y8 - x17)
Y16(y1 -x10)+Y26(y2 - x11)+Y36(y3 - x12)+Y46(y4 - x13)+Y56(y5 - x14)+Y66(y6 - x15)+Y67(y7 - x16)+Y68(y8 - x17)
Y17(y1 -x10)+Y27(y2 - x11)+Y37(y3 - x12)+Y47(y4 - x13)+Y57(y5 - x14)+Y67(y6 - x15)+Y77(y7 - x16)+Y78(y8 - x17)
Y18(y1 -x10)+Y28(y2 - x11)+Y38(y3 - x12)+Y48(y4 - x13)+Y58(y5 - x14)+Y68(y6 - x15)+Y78(y7 - x16)+Y88(y8 - x17)
Y19(y1 -x10)+Y29(y2 - x11)+Y39(y3 - x12)+Y49(y4 - x13)+Y59(y5 - x14)+Y69(y6 - x15)+Y79(y7 - x16)+Y89(y8 - x17)
+Y19 (y9 - x18)
+Y29 (y9 - x18)
+Y39 (y9 - x18)
+Y49 (y9 - x18)
+Y59 (y9 - x18)
+Y69 (y9 - x18)
+Y79 (y9 - x18)
+Y89 (y9 - x18)
+Y99 (y9 - x18)

= -

Y11 x10 +Y12 x11 +Y13 x12 +Y14 x13 +Y15 x14 +Y16 x15 +Y17 x16 +Y18 x17 +Y19 x18
Y12 x10 +Y22 x11 +Y23 x12 +Y24 x13 +Y25 x14 +Y26 x15 +Y27 x16 +Y28 x17 +Y29 x18
Y13 x10 +Y23 x11 +Y33 x12 +Y34 x13 +Y35 x14 +Y36 x15 +Y37 x16 +Y38 x17 +Y39 x18
Y14 x10 +Y24 x11 +Y34 x12 +Y44 x13 +Y45 x14 +Y46 x15 +Y47 x16 +Y48 x17 +Y49 x18
Y15 x10 +Y25 x11 +Y35 x12 +Y45 x13 +Y55 x14 +Y56 x15 +Y57 x16 +Y58 x17 +Y59 x18
Y16 x10 +Y26 x11 +Y36 x12 +Y46 x13 +Y56 x14 +Y66 x15 +Y67 x16 +Y68 x17 +Y69 x18
Y17 x10 +Y27 x11 +Y37 x12 +Y47 x13 +Y57 x14 +Y67 x15 +Y77 x16 +Y78 x17 +Y79 x18
Y18 x10 +Y28 x11 +Y38 x12 +Y48 x13 +Y58 x14 +Y68 x15 +Y78 x16 +Y88 x17 +Y89 x18
Y19 x10 +Y29 x11 +Y39 x12 +Y49 x13 +Y59 x14 +Y69 x15 +Y79 x16 +Y89 x17 +Y99 x18

Y11 y1 +Y12 y2 +Y13 y3 +Y14 y4 +Y15 y5 +Y16 y6 +Y17 y7 +Y18 y8 +Y19 y9
Y12 y1 +Y22 y2 +Y23 y3 +Y24 y4 +Y25 y5 +Y26 y6 +Y27 y7 +Y28 y8 +Y29 y9
Y13 y1 +Y23 y2 +Y33 y3 +Y34 y4 +Y35 y5 +Y36 y6 +Y37 y7 +Y38 y8 +Y39 y9
Y14 y1 +Y24 y2 +Y34 y3 +Y44 y4 +Y45 y5 +Y46 y6 +Y47 y7 +Y48 y8 +Y49 y9
Y15 y1 +Y25 y2 +Y35 y3 +Y45 y4 +Y55 y5 +Y56 y6 +Y57 y7 +Y58 y8 +Y59 y9
Y16 y1 +Y26 y2 +Y36 y3 +Y46 y4 +Y56 y5 +Y66 y6 +Y67 y7 +Y68 y8 +Y69 y9
Y17 y1 +Y27 y2 +Y37 y3 +Y47 y4 +Y57 y5 +Y67 y6 +Y77 y7 +Y78 y8 +Y79 y9
Y18 y1 +Y28 y2 +Y38 y3 +Y48 y4 +Y58 y5 +Y68 y6 +Y78 y7 +Y88 y8 +Y89 y9
Y19 y1 +Y29 y2 +Y39 y3 +Y49 y4 +Y59 y5 +Y69 y6 +Y79 y7 +Y89 y8 +Y99 y9

```
Ob1 = ( a11 - Xa1  - Y(1,1) )
Ob2 = ( a12 - Xa2  - Y(1,2) )
Ob3 = ( a13 - Xa3  - Y(1,3) )
Ob4 = ( a14 - Xa4  - Y(1,4) )
Ob5 = ( a15 - Xa5  - Y(1,5) )
Ob6 = ( a16 - Xa6  - Y(1,6) )
Ob7 = ( a17 - Xa7  - Y(1,7) )
Ob8 = ( a18 - Xa8  - Y(1,8) )
Ob9 = ( a19 - Xa9  - Y(1,9) )

Ob1s = -Y(1,1)
Ob2s = -Y(1,2)
Ob3s = -Y(1,3)
Ob4s = -Y(1,4)
Ob5s = -Y(1,5)
Ob1ss =- Y(1,6)
Ob2ss =- Y(1,7)
Ob3ss =- Y(1,8)
Ob4ss =- Y(1,9)
%-----------
Ob10= ( a21  - Xa10  - Y(1,2) )
Ob11= ( 0    - Xa11  - Y(2,2) )
Ob12= ( a23  - Xa12  - Y(2,3) )
Ob13= ( 0    - Xa13  - Y(2,4) )
Ob14= ( 0    - Xa14  - Y(2,5) )
Ob15= ( 0    - Xa15  - Y(2,6) )
Ob16= ( 0    - Xa16  - Y(2,7) )
Ob17= ( 0    - Xa17  - Y(2,8) )
Ob18= ( a29  - Xa18  - Y(2,9) )

Ob6s  = -Y(1,2)
Ob7s  = -Y(2,2)
Ob8s  = -Y(2,3)
Ob9s  = -Y(2,4)
Ob10s =- Y(2,5)
Ob6ss =- Y(2,6)
Ob7ss =- Y(2,7)
Ob8ss =- Y(2,8)
Ob9ss =- Y(2,9)
%----------
Ob19=( 0     - Xa19 - Y(1,3) )
Ob20=( a32   - Xa20 - Y(2,3) )
Ob21=( 0     - Xa21 - Y(3,3) )
Ob22=( a34   - Xa22 - Y(3,4) )
Ob23=( 0     - Xa23 - Y(3,5) )
Ob24=( 0     - Xa24 - Y(3,6) )
Ob25=( 0     - Xa25 - Y(3,7) )
Ob26=( a38   - Xa26 - Y(3,8) )
Ob27=( 0     - Xa27 - Y(3,9) )

Ob11s  = -Y(1,3)
Ob12s  = -Y(2,3)
Ob13s  = -Y(3,3)
Ob14s  = -Y(3,4)
Ob15s  = -Y(3,5)
Ob11ss =- Y(3,6)
Ob12ss =- Y(3,7)
Ob13ss =- Y(3,8)
Ob14ss = -Y(3,9)

%----------
Ob28=( 0    - Xa28  - Y(1,4) )
Ob29=( 0    - Xa29  - Y(2,4) )
Ob30=( a43  - Xa30  - Y(3,4) )
Ob31=( 0    - Xa31  - Y(4,4) )
Ob32=( a45  - Xa32  - Y(4,5) )
Ob33=( 0    - Xa33  - Y(4,6) )
Ob34=( a47  - Xa34  - Y(4,7) )
Ob35=( 0    - Xa35  - Y(4,8) )
Ob36=( 0    - Xa36  - Y(4,9) )

Ob16s  = -Y(1,4)
Ob17s  = -Y(2,4)
Ob18s  = -Y(3,4)
Ob19s  = -Y(4,4)
Ob20s  = -Y(4,5)
Ob16ss =- Y(4,6)
Ob17ss =- Y(4,7)
Ob18ss =- Y(4,8)
Ob19ss =- Y(4,9)
%----------
Ob37=( 0    - Xa37  - Y(1,5) )
Ob38=( 0    - Xa38  - Y(2,5) )
Ob39= (0    - Xa39  - Y(3,5) )
Ob40=( a54  - Xa40  - Y(4,5) )
Ob41=( 0    - Xa41  - Y(5,5) )
Ob42=( a56  - Xa42  - Y(5,6) )
Ob43=( 0    - Xa43  - Y(5,7) )
Ob44=( 0    - Xa44  - Y(5,8) )
Ob45=( 0    - Xa45  - Y(5,9) )

Ob21s  = -Y(1,5)
Ob22s  = -Y(2,5)
Ob23s  = -Y(3,5)
Ob24s  = -Y(4,5)
Ob25s  = -Y(5,5)
Ob21ss =- Y(5,6)
Ob22ss =- Y(5,7)
Ob23ss =- Y(5,8)
Ob24ss =- Y(5,9)
%----------
Ob46= ( 0    - Xa46 - Y(1,6) )
Ob47= ( 0    - Xa47 - Y(2,6) )
Ob48= ( 0    - Xa48 - Y(3,6) )
Ob49= ( 0    - Xa49 - Y(4,6) )
Ob50= ( a65  - Xa50 - Y(5,6) )
Ob51= ( 0    - Xa51 - Y(6,6) )
Ob52= ( a67  - Xa52 - Y(6,7) )
Ob53= ( 0    - Xa53 - Y(6,8) )
Ob54= ( 0    - Xa54 - Y(6,9) )

Ob26s  = -Y(1,6)
Ob27s  = -Y(2,6)
Ob28s  = -Y(3,6)
Ob29s  = -Y(4,6)
Ob30s  = -Y(5,6)
Ob26ss =- Y(6,6)
Ob27ss =- Y(6,7)
Ob28ss =- Y(6,8)
Ob29ss =- Y(6,9)

%----------
Ob55= ( 0    - Xa55 - Y(1,7) )
Ob56= ( 0    - Xa56 - Y(2,7) )
Ob57= ( 0    - Xa57 - Y(3,7) )
Ob58= ( a74  - Xa58 - Y(4,7) )
Ob59= ( 0    - Xa59 - Y(5,7) )
Ob60= ( a76  - Xa60 - Y(6,7) )
Ob61= ( 0    - Xa61 - Y(7,7) )
Ob62= ( a78  - Xa62 - Y(7,8) )
Ob63= ( 0    - Xa63 - Y(7,9) )

Ob31s  = -Y(1,7)
Ob32s  = -Y(2,7)
Ob33s  = -Y(3,7)
Ob34s  = -Y(4,7)
Ob35s  = -Y(5,7)
Ob31ss =- Y(6,7)
Ob32ss =- Y(7,7)
Ob33ss =- Y(7,8)
Ob34ss =- Y(7,9)

%----------
Ob64= ( 0    - Xa64 - Y(1,8) )
Ob65= ( 0    - Xa65 - Y(2,8) )
Ob66= ( a83  - Xa66 - Y(3,8) )
Ob67= ( 0    - Xa67 - Y(4,8) )
Ob68= ( 0    - Xa68 - Y(5,8) )
Ob69= ( 0    - Xa69 - Y(6,8) )
Ob70= ( a87  - Xa70 - Y(7,8) )
Ob71= ( 0    - Xa71 - Y(8,8) )
Ob72= ( a89  - Xa72 - Y(8,9) )

Ob36s  = -Y(1,8)
Ob37s  = -Y(2,8)
Ob38s  = -Y(3,8)
Ob39s  = -Y(4,8)
Ob40s  = -Y(5,8)
Ob36ss =- Y(6,8)
Ob37ss =- Y(7,8)
Ob38ss =- Y(8,8)
Ob39ss =- Y(8,9)

%----------
Ob73= ( a91  - Xa73 - Y(1,9) )
Ob74= ( a92  - Xa74 - Y(2,9) )
Ob75= ( a93  - Xa75 - Y(3,9) )
Ob76= ( a94  - Xa76 - Y(4,9) )
Ob77= ( a95  - Xa77 - Y(5,9) )
Ob78= ( a96  - Xa78 - Y(6,9) )
Ob79= ( a97  - Xa79 - Y(7,9) )
Ob80= ( a98  - Xa80 - Y(8,9) )
Ob81= ( a99  - Xa81 - Y(9,9) )

Ob41s  = -Y(1,9)
Ob42s  = -Y(2,9)
Ob43s  = -Y(3,9)
Ob44s  = -Y(4,9)
Ob45s  = -Y(5,9)
Ob41ss =- Y(6,9)
Ob42ss =- Y(7,9)
Ob43ss =- Y(8,9)
Ob44ss =- Y(9,9)

%----------

%----------
```

xdot(1) = a11*x(1) + a12*x(2) + a13*x(3)+ a14*x(4)+ a15*x(5) + a16*x(6) + a17*x(7) + a18*x(8) + a19*x(9)
+ Xa1*x(10) + Xa2*x(11) + Xa3*x(12) + Xa4*x(13) + Xa5*x(14) + Xa6*x(15) + Xa7*x(16) + Xa8*x(17) + Xa9*x(18)

xdot(2)= a21* x(1) + a23*x(3) + a29* x(9)
+ Xa10*x(10) + Xa11*x(11) + Xa12*x(12) + Xa13*x(13) + Xa14*x(14) + Xa15*x(15) + Xa16*x(16) + Xa17*x(17) + Xa18*x(18)

xdot(3)= a32*x(2) + a34* x(4) + a38*x(8)
+ Xa19*x(10) + Xa20*x(11) + Xa21*x(12) + Xa22*x(13) + Xa23*x(14) + Xa24*x(15) + Xa25*x(16) + Xa26*x(17) + Xa27*x(18)

xdot(4)= a43*x(3) + a45*x(5) + a47*a7
+ Xa28*x(10) + Xa29*x(11) + Xa30*x(12) + Xa31*x(13) + Xa32*x(14) + Xa33*x(15) + Xa34*x(16) + Xa35*x(17) + Xa36*x(18)

xdot(5)= a54* x(4) + a56*x(6)
+ Xa37*x(10) + Xa38*x(11) + Xa39*x(12) + Xa40*x(13) + Xa41*x(14) + Xa42*x(15) + Xa43*x(16) + Xa44*x(17) + Xa45*x(18)

xdot(6)= a65*x(5) + a67*x(7)
+ Xa46*x(10) + Xa47*x(11) + Xa48*x(12) + Xa49*x(13) + Xa50*x(14) + Xa51*x(15) + Xa52*x(16) + Xa53*x(17) + Xa54*x(18)

xdot(7)= a74* x(4) + a76* x(6) + a78*x(8)
+ Xa55*x(10) + Xa56*x(11) + Xa57*x(12) + Xa58*x(13) + Xa59*x(14) + Xa60*x(15) + Xa61*x(16) + Xa62*x(17) + Xa63*x(18)

xdot(8) = a83*x(3) + a87*x(7) + a89*x(9)
+ Xa64*x(10) + Xa65*x(11) + Xa66*x(12) + Xa67*x(13) + Xa68*x(14) + Xa69*x(15) + Xa70*x(16) + Xa71*x(17) + Xa72*x(18)

xdot(9) = a91*x(1) + a92*x(2) + a93*x(3)+ a94*x(4)+ a95*x(5) + a96*x(6) + a97*x(7) + a98*x(8) + a99*x(9)
+ Xa73*x(10) + Xa74*x(11) + Xa75*x(12) + Xa76*x(13) + Xa77*x(14) + Xa78*x(15) + Xa79*x(16) + Xa80*x(17) + Xa81*x(18)

xdot(10) = Ob1*x(10) + Ob2*x(11) + Ob3*x(12) + Ob4*x(13) + Ob5*x(14)+ Ob6*x(15) + Ob7*x(16) + Ob8*x(17) + Ob9*x(18)
+ Ob1s*x(1) + Ob2s*x(2) + Ob3s*x(3) + Ob4s*x(4) + Ob5s*x(5)+ Ob1ss*x(6)+ Ob2ss*x(7) + Ob3ss*x(8) + Ob4ss*x(9)

xdot(11) = Ob10*x(10) + Ob11*x(11) + Ob12*x(12) + Ob13*x(13) + Ob14*x(14)+ Ob15*x(15)+ Ob16*x(16) + Ob17*x(17)+ Ob18*x(18)
+ Ob6s*x(1) + Ob7s*x(2) + Ob8s*x(3) + Ob9s*x(4) + Ob10s*x(5)+ Ob6ss*x(6)+ Ob7ss*x(7) + Ob8ss*x(8)+ Ob9ss*x(9)

xdot(12) = Ob19*x(10) + Ob20*x(11) + Ob21*x(12) + Ob22*x(13) + Ob23*x(14)+ Ob24*x(15)+ Ob25*x(16) + Ob26*x(17)
+ Ob27*x(18)+ Ob11s*x(1) + Ob12s*x(2) + Ob13s*x(3) + Ob14s*x(4) + Ob15s*x(5)+ Ob11ss*x(6)+ Ob12ss*x(7)
+ Ob13ss*x(8)+ Ob14ss*x(9)

xdot(13) = Ob28*x(10) + Ob29*x(11) + Ob30*x(12) + Ob31*x(13) + Ob32*x(14)+ Ob33*x(15) + Ob34*x(16) + Ob35*x(17) + Ob36*x(18)
+ Ob16s*x(1) + Ob17s*x(2) + Ob18s*x(3) + Ob19s*x(4) + Ob20s*x(5)+ Ob16ss*x(6)+ Ob17ss*x(7)+ Ob18ss*x(8)+ Ob19ss*x(9)

xdot(14) = Ob37*x(10) + Ob38*x(11) + Ob39*x(12) + Ob40*x(13) + Ob41*x(14)+ Ob42*x(15)+ Ob43*x(16)
+ Ob44*x(17)+ Ob45*x(18)+ Ob21s*x(1) + Ob22s*x(2) + Ob23s*x(3) + Ob24s*x(4) + Ob25s*x(5)+ Ob21ss*x(6)
+ Ob22ss*x(7)+ Ob23ss*x(8)+ Ob24ss*x(9)

xdot(15) = Ob46*x(10) + Ob47*x(11) + Ob48*x(12) + Ob49*x(13) + Ob50*x(14)+ Ob51*x(15)+ Ob52*x(16) + Ob53*x(17)+ Ob54*x(18)
+ Ob26s*x(1) + Ob27s*x(2) + Ob28s*x(3) + Ob29s*x(4) + Ob30s*x(5)+ Ob26ss*x(6) + Ob27ss*x(7) + Ob28ss*x(8) + Ob29ss*x(9)

xdot(16) = Ob55*x(10) + Ob56*x(11) + Ob57*x(12) + Ob58*x(13) + Ob59*x(14)+ Ob60*x(15)+ Ob61*x(16) + Ob62*x(17)+ Ob63*x(18)
+ Ob31s*x(1) + Ob32s*x(2) + Ob33s*x(3) + Ob34s*x(4) + Ob35s*x(5)+ Ob31ss*x(6) + Ob32ss*x(7) + Ob33ss*x(8) + Ob34ss*x(9)

xdot(17) = Ob64*x(10) + Ob65*x(11) + Ob66*x(12) + Ob67*x(13) + Ob68*x(14)+ Ob69*x(15)+ Ob70*x(16) + Ob71*x(17)+ Ob72*x(18)
+ Ob36s*x(1) + Ob37s*x(2) + Ob38s*x(3) + Ob39s*x(4) + Ob40s*x(5)+ Ob36ss*x(6) + Ob37ss*x(7) + Ob38ss*x(8) + Ob39ss*x(9)

xdot(18) = Ob73*x(10) + Ob74*x(11) + Ob75*x(12) + Ob76*x(13) + Ob77*x(14)+ Ob78*x(15)+ Ob79*x(16) + Ob80*x(17)+ Ob81*x(18)
+ Ob41s*x(1) + Ob42s*x(2) + Ob43s*x(3) + Ob44s*x(4) + Ob45s*x(5)+ Ob41ss*x(6) + Ob42ss*x(7) + Ob43ss*x(8) + Ob44ss*x(9)

To close the loop,we set the negative feed back as

y1 = -x1,
y2 = -x2
y3 = -x3,
y4 = -x4
y5 = -x5,
y6 = -x6
y7 = -x7,
y8 = -x8
y9 = -x9,

We can obtain the coefficients Obn and Obnss

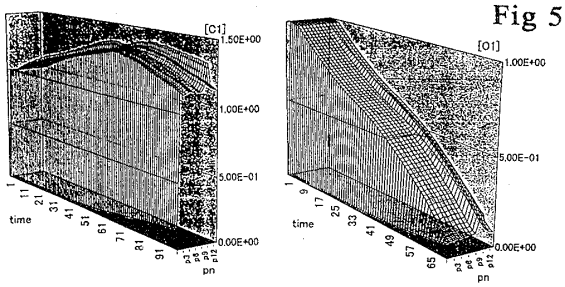

Fig 5

2. Results.

Fig 5 shows the temporal changes in [C1] and [O1] with changes in weighting coefficients for the control inputs un. Significant changes can be observed at particular pn. The present evaluation when extended will be available for predicting the noise filtering function of biomembranes.

3.Reference

1. Matkes.T.N and Jones.W. J.Gen. Phys. vol 99. pp 367. 1992.