Application of AI Techniques for Modelling Motion of a Snake

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Abstract
The study of biomimetic robots has been around for a long while; a particular attention has been given to robots that can operate autonomously in real-world environments. The aim of such robots would be to aid, or replace humans in dangerous or perilous tasks. An example that comes to mind is the bomb disposal, bush fires or detection robot controlled by a human operator. Our challenge in general and especially the focus of this research is to duplicate animal locomotion, and the decision-making processes. By studying the physiological (biological) processes we want to encapsulate this behaviour into readily available software, computer and electro-mechanical technology.

Keywords: Robotic motion, Quaternion, Genetic algorithm, Immuno-Computing algorithm, Anticipatory system.

1 Introduction

Study of biological snake locomotion has been carried out resulting in a variety of locomotion strategies for different environments (Delcomyn, 1980), (Ayers & Rudolph, 2002). The different strategies include; sliding, concertina progression, rectilinear motion and forms of undulation (Kato, Ayers & Morikawa, 2004). A snake robot, for example, designed for search and rescue is an interesting topic as the robot needs to continuously adapt to a changing environment. A good discussion and various scenarios are presented by Liljebäck (2005), Liljebäck, Stavdahl, Pettersen (2005), as well as Jelonek and Komosinski (2006), Miller (2007). From our perspective, autonomy and flexibility of robotic snake's motion is essential. These attributes are characteristic to all anticipatory systems. Therefore, in this study we shall explore such anticipatory behaviour where the main aim would be to allow the robot snake to evolve using combination of Genetic and IC algorithms (GA/IC) as initially discussed by Tarakanov et al. (2003). In our approach various constraints are introduced in a gradual manner. In our experiments, these constraints take the form of a flat-space to inclines then considerations are given to different levels of friction and finally the energy balance for various tasks is computed.

Artificial Intelligence is about modelling of natural systems and therefore we choose to use a combination of GA's and IC, in order to evolve the locomotion of the robot. The simulation framework called "Framsticks" (Ulatowski & Komosinski, 1999, 2007) allows us to constructs segments of the snake and imposes environmental restrictions. Construction will consist of segments, much like the segments of amino acid that combine to form peptide bonds and finally the peptide chain. As in protein structure and kinematics we will use quaternion formalism to describe angles and rotation of each segment of the snake, finally culminating into efficient locomotion behaviours that have evolved and adapted to its environment. Using the IC algorithm, our chromosome will consist of parameters relating to protein folding, such as number of links, the angles of rotation (considered as the states of each segment of the snake), energy factors, quaternion multiplication and other controls (Tarakanov et al. 2003). The GA/IC will optimise these parameters (chromosomes, genes alleles etc) so as to produce an efficient mechanism for forward motion, given external constraints. Once this optimal set is achieved the snake brain can store this and other optimal sets (depending on multiple constraints) in a neural network 2D map or co-operative Extended Kohonen Maps (Low et al., 2005). The simulation framework allows us to construct such scenarios and experiment with the various mechanisms for GA/IC optimisation and neural network structures. The real challenge will be to construct the hardware counterparts.

2 Modelling the Formal Protein (FP) Transformations

The explanation below presents a skeletal description of the FP model and its transformation process only. Several sub-steps have been deliberately omitted to simplify the process.

2.1 The Definition of the Structure of Proteins

The structure of proteins alanine and glycine forming peptide bonds (highlighted in red). Many such peptide bonds form peptide chains (Tarakanov et al. 2003). The quaternions that describe the protein structure are shown below.

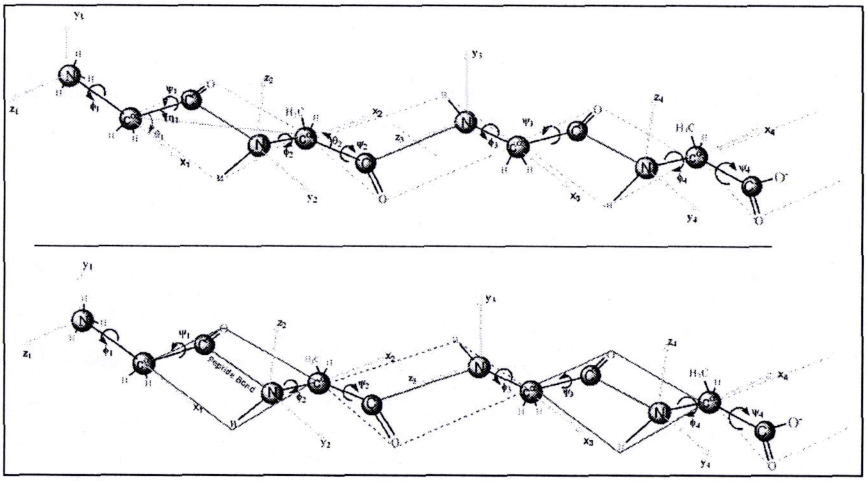

Figure 1: The structure of proteins alanine and glycine forming peptide bonds.

2.2 Calculation of Quaternions that Describe the Protein Structure

The quaternions that describe the protein structure shown in the diagram above and the transition between coordinate systems are given by:

$$q_1 = [f, y, q, h] = -\cos\left[\frac{q}{2}\right]\sin\left[\frac{y+f}{2}\right], \tag{1}$$

$$q_2 = [f, y, q, h] = \sin\left[\frac{q}{2}\right]\cos\left[\frac{h}{2}\right]\cos\left[\frac{y+f}{2}\right] + \sin\left[\frac{q}{2}\right]\sin\left[\frac{h}{2}\right]\cos\left[\frac{y-f}{2}\right], \tag{2}$$

$$q_3 = [f, y, q, h] = \cos\left[\frac{q}{2}\right]\sin\left[\frac{h}{2}\right]\cos\left[\frac{y+f}{2}\right] - \sin\left[\frac{q}{2}\right]\cos\left[\frac{h}{2}\right]\cos\left[\frac{y-f}{2}\right], \tag{3}$$

$$q_4 = [f, y, q, h] = -\sin\left[\frac{q}{2}\right]\sin\left[\frac{y-f}{2}\right] \tag{4}$$

2.3 Designation of the Quaternion Q

This step involves designation of the quaternion Q, which is the sum of the q's (Tarakanov et al, 2003).

$$Q_k(\varphi_k, \psi_k) = (q_1, q_2, q_3, q_4)_{segment\_k} \tag{5}$$

2.4 Definition of Links in the Chain of Proteins

Therefore the chain contains the quaternions Q_1, Q_2, Q_3 for each link between the segments (of the snake) as indicated in the Figure 2.

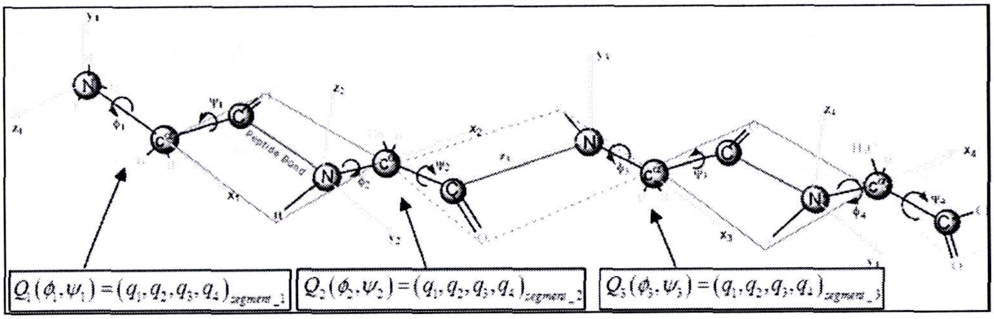

Figure 2: The chain of proteins

2.5 Specification of the Chain of Peptides

The set of such a peptide chain as in the diagram above is given as:
$Q=\{Q_0,Q_k\}$, where $Q_0=Q_1Q_2......Q_n$ and where $n=\#links$ (6)

2.6 5-Tuple Computation of the FP

The formal protein is then described by a set of 5 numbers (5-tuple),
$P=\langle n,U,Q,V,v\rangle$ where, (7)
$n=\#of\ links,$
$U=\{\phi_k,\psi_k\},k=1...n$
$Q=\{Q_0,Q_k\},$
$V=\{v_{ij}\},j\geq i,i=1,2,3,4$
and
$q_{1..4}$ = see section 2.2 above

3 Case Studies

3.1 Case 1: Procedural Steps for FP with a Single Peptide Bond

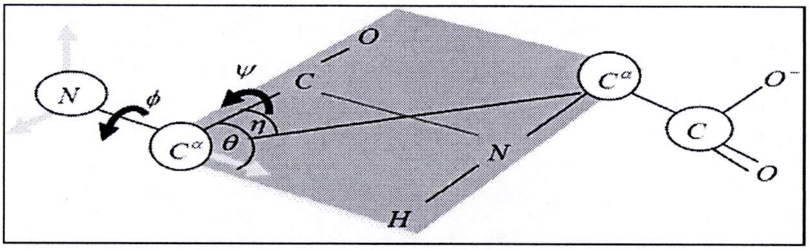

Figure 3: FP with only one peptide bond

At the beginning we assume that our FP (Tarakanov, 2003, p.18) has only one peptide bond thus $n=1$. Also, let us set, $\theta=\eta=0$, $\phi=-\pi$ and let ψ be the variable. We then compute controls for our robotic snake in the following steps:

a. Compute

$$Q(\psi)=(q_1,q_2,q_3,q_4)=\left(\cos\frac{\psi}{2},\sin\frac{\psi}{2},0,0\right),-\pi\leq\psi\leq\pi,\cos\frac{\psi}{2}>0.$$

This is done by substituting the value for phi, eta and theta, into the equations for $q_{1,2,3,4}$.
Now let this FP have a single non-zero control v_{11},

$$\therefore\ V = \{v_{11}\} = \begin{bmatrix} v_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}. \tag{8}$$

b. The free energy is given by $v = -\sum_{j \geq i} v_{ij} q_i q_j$. If we are assuming only one non-zero control then the free energy is:

$$v = -v_{11}\, q_1\, q_1 = -v_{11}\, Cos^2 \frac{\psi}{2}. \tag{9}$$

c. Take the derivatives of the free energy with respect to ψ:

$$\partial_{\psi} v = \frac{v_{11}}{2} Sin\psi$$

$$\partial_{\psi,\psi} v = \frac{v_{11}}{2} Cos\psi$$

and stable states are found by equating the first derivative to zero. The controls v_{ij} could possibly represent any characteristic of the segment, friction, current consumption from motors or sensors/actuators, communication efficiency, etc. All these parameters in our case refer to the robotic snake. In general the free energy is given by:

$$\begin{aligned} v = -\big[& v_{11}q_1q_1 + v_{12}q_1q_2 + v_{13}q_1q_3 + v_{14}q_1q_4 + \ldots \\ & \ldots\ldots v_{22}q_2q_2 + v_{23}q_2q_3 + v_{24}q_2q_4 + \ldots. \\ & \ldots\ldots v_{33}q_3q_3 + v_{34}q_3q_4 + v_{44}q_4q_4 \big]. \end{aligned} \tag{10}$$

As mentioned by Tarakanov, the free energy is computed as the sum of products of quaternions and given weights. The weights are the controls and the torsion angles the inner states: inputs and outputs respectively. How do we decide which controls (v_{ij}) remains an issue for our further experimental investigation.

3.2 Case 3: Procedural Steps (see Table 2 & 3) for FP with Three Peptide Bonds

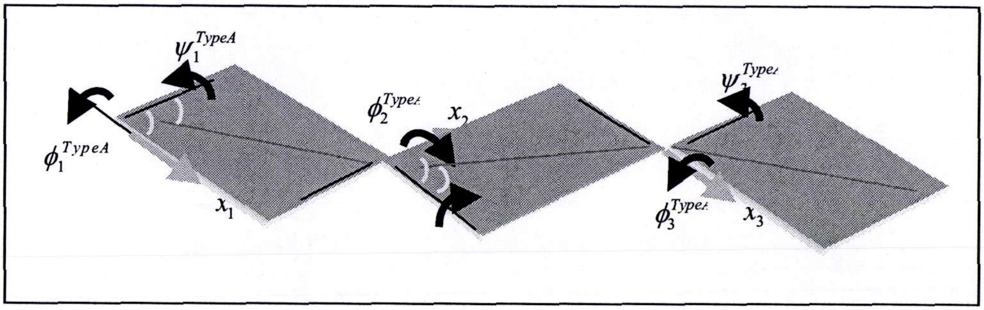

Figure 4: FP with three peptide bonds

The general term for the above FP structure (Tarakanov et al. 2003, p.18-20) is an **n-peptide**: in this case it is called 3-peptide, where 3 denotes the number of links. Some candidates for nomenclature that separate this n-peptide from other n-peptides could be: 3-peptide-1, $3p1$, Type **A** n-peptide or Type B n-peptide. This means we can assign characteristics to the type of n-peptide as in B-cells or T-cells or variations thereof.

Let us calculate all the parameters for the 3-peptide:

Table 1: 3 Peptide Bonds

Segment 1 , n = 1	Segment 2, n = 2	Segment 3 , n = 3
Given $\theta_{1,2,3}^{TypeA} = \eta_{1,2,3}^{TypeA} = 0$		
Given $\psi_1^{TypeA} = \phi_1^{TypeA} - \pi$	Given $\psi_2^{TypeA} = \phi_2^{TypeA} - \pi$	Given $\psi_3^{TypeA} = \phi_3^{TypeA} - \pi$
Calculated $Q_1^{TypeA} = \left(Cos\,\phi_1^{TypeA}, Sin\,\phi_1^{TypeA}, 0, 0\right)$	Calculated $Q_2^{TypeA} = \left(Cos\,\phi_2^{TypeA}, Sin\,\phi_2^{TypeA}, 0, 0\right)$	Calculated $Q_3^{TypeA} = \left(Cos\,\phi_3^{TypeA}, Sin\,\phi_3^{TypeA}, 0, 0\right)$
Given Non-zero control for segment 1 (see equation 8) $\begin{bmatrix} V_{11_{seg1}}^{TypeA} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$	Given Non-zero control for segment 2 $\begin{bmatrix} V_{11_{seg2}}^{TypeA} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$	Given Non-zero control for segment 3 $\begin{bmatrix} V_{11_{seg3}}^{TypeA} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$
Free energy for segment 1	Free energy for segment 2	Free energy for segment 3

$\nu\left(Q_1^{TypeA}\right) = -\nu_{11_{seg1}}^{TypeA} \cos^2 \phi_1^{TypeA}$	$\nu\left(Q_2^{TypeA}\right) = -\nu_{11_{seg2}}^{TypeA} \cos^2 \phi_2^{TypeA} =$	$\nu\left(Q_3^{TypeA}\right) = -\nu_{11_{seg3}}^{TypeA} \cos^2 \phi_3^{TypeA}$

Assign the Binding Matrix with One non-zero term

$$W_{1\to2} = \begin{bmatrix} w_{11_{seg1\to2}}^{TypeA} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \qquad W_{2\to3} \begin{bmatrix} w_{11_{seg2\to3}}^{TypeA} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

between segments 1 & 2

between segments 2 & 3

The Bound Energy (BE) of the complex

$$\boxed{\begin{aligned} \mathrm{BE}_{1\to2} &= -\left(Q_1^{TypeA}\right)^T W_{1\to2}\ Q_2^{TypeA} \\ &= -w_{11_{seg1\to}}^{TypeA}\, Cos\phi_1^{TypeA} Cos\phi_2^{TypeA} \end{aligned}} \qquad \boxed{\begin{aligned} \mathrm{BE}_{2\to3} &= -\left(Q_2^{TypeA}\right)^T W_{2\to3}\ Q_3^{TypeA} \\ &= -w_{11_{seg2\to3}}^{TypeA}\, Cos\phi_2^{TypeA} Cos\phi_3^{TypeA} \end{aligned}}$$

The total energy of the system

$$\begin{aligned} \mathrm{Energy}_{1\to2} &= \nu\left(Q_1^{TypeA}\right) + \nu\left(Q_2^{TypeA}\right) + \left(Q_1^{TypeA}\right)^T W_{1\to2}\ Q_2^{TypeA} \\ &= -\nu_{11_{seg1}}^{TypeA} Cos^2\phi_1^{TypeA} - \text{[illegible]}\ Cos^2\phi_2^{TypeA} - w_{11_{seg1\to}}^{TypeA} Cos\phi_1^{TypeA} Cos\phi_2^{TypeA} \end{aligned}$$

$$\begin{aligned} \mathrm{Energy}_{2\to3} &= \nu\left(Q_2^{TypeA}\right) + \nu\left(Q_3^{TypeA}\right) + \left(Q_2^{TypeA}\right)^T W_{2\to3}\ Q_3^{TypeA} \\ &= -\ \text{[illegible]}\ Cos^2\phi_2^{TypeA} - \nu_{11_{seg3}}^{TypeA} Cos^2\phi_3^{TypeA} - w_{11_{seg\to}}^{TypeA} Cos\phi_2^{TypeA} Cos\phi_3^{TypeA} \end{aligned}$$

The controls of the system represented by $-\nu_{11_{seg1}}^{TypeA}, -\nu_{11_{seg2}}^{TypeA}$, & $-\nu_{11_{seg3}}^{TypeA}$ can represent some characteristic of the system and particular about the segment. In the example above only matrix element (1,1) is chose to be non-zero. The partial differentials of the Energy for each segment combination are then calculated as:

$$\begin{bmatrix} \partial_{\phi_1^{TypeA}} \mathrm{Energy}_{1\to2} & \partial_{\phi_2^{TypeA}} \mathrm{Energy}_{1\to2} \\ \partial_{\phi_2^{TypeA}} \mathrm{Energy}_{2\to3} & \partial_{\phi_3^{TypeA}} \mathrm{Energy}_{2\to3} \end{bmatrix} \tag{11}$$

4 Conclusion and Future Work

In our simulation experiments, the movement of robotic segments is coordinated by sensors/actuators forming a sensor network using the described GA/IC algorithm techniques. Current work involves multi-constraint optimisation and a blueprint for a virtual snake with its segments evolving in parallel and exchanging genetic information. For machine learning tasks and sensory-motor control we adapt co-operative Extended Kohonen Maps (EKMs). Preliminary results demonstrate that the indirect mapping using the EKMs provides an effective control and feedback mechanism for robotic segments operating in a continuous sensory control space. By training the control parameters, a faster convergence can be obtained with procedures such as the recursive least squares method. The coordination of the sensory and movement control system can then be enhanced by the co-operation of clusters of self-organising EKMs to adapt to actively changing conditions in the robotic snake's environment. Future experimentation will involve investigation how we can better optimise the time taken in achieving coordinated movement and communication between the segments (components) via sensor/actuator network system of the snake.

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