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Analysis of Rectilinear Snake Robots in ISO 8608 Random Surface

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Abstract--- *This paper deals with the analytical modeling of rectilinear snake robots. During recent times snake robots have created much interest among researchers. The rectilinear pattern gait is one of the four biological snake locomotion modes. . Rectilinear snakes have been widely used in rescue operations especially in rough terrains especially in narrow spaces where human intervention is not easy. Computational analysis of rectilinear motion is done using MATLAB for ISO 8608 random surface.*

Keywords--- *Rectilinear, Random Surface, Friction, Spring-Mass System.*

I. INTRODUCTION

Bio-inspired robots have been used in many practical applications There are many recent successful attempts to make crawling robots. The snake robots are such robots which provide advantageous properties in hard to reach areas because of its good skeletal structure. Research on snake robots is inspired by the robust motion capabilities of biological snakes. The snake motion is very stable because during its motion it has body parts in the contact with the surface. This area of research is in most cases only in theoretical level since the snake-like robots are very difficult to design and control.

The four biological snake locomotion are:

a. Lateral undulation
b. Concertina locomotion
c. Rectilinear crawling
d. Side winding

The rectilinear locomotion mode is usually the pattern gait by heavy snakes which are not possible to move by undulation. This rectilinear locomotion mode is used to achieve desired model of snake robots. The mathematical model is developed using MATLAB. Theoretical level analysis has been done where the model consists of identical masses and passive bonds.

II. SPRING-MASS MODEL

The rectilinear locomotion can be realized using the spring–mass model consisting of massless spring and dampers between segments of snake robots. Figure 1 shows the simplified model of the snake consisting of N consecutive masses of the weight m.

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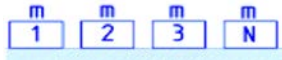

Figure 1: Simplified model of the snake

For having a simplified analysis we simplify the above N mass model as a two mass model as shown in Figure 2 and spring damper N mass model is shown in Figure 3.

Figure 2: Two mass model of the snake

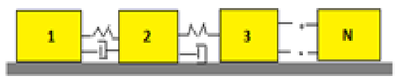

Figure 3: Spring- damper N masses mechanical system

This Spring-damper model depicts the snake rectilinear motion. Next, the same propulsive force affects n-th moving mass; therefore each mass moves the same time t. The interaction between snake robot and dry surface on which it moves is modeled as Coulomb friction. The example of motion sequence of 5-mass mechanical system is shown on the Figure 4.

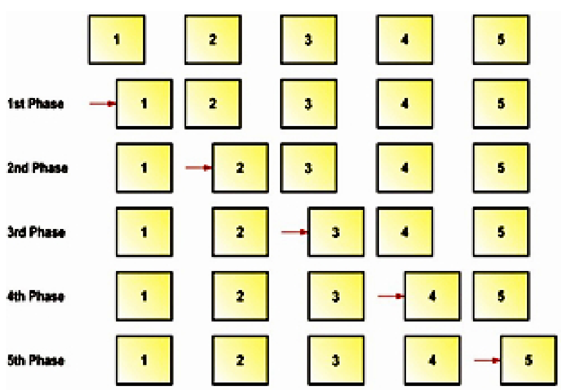

Figure 4: Sequence of snake robot rectilinear motion

As can be seen on the Figure 4, during one motion cycle still only one mass moves while other are at rest. The actuators between static masses operate so, that static masses behave as one mass according to Figure 6.

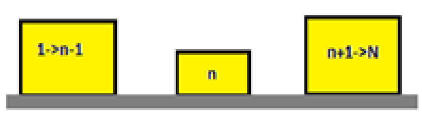

Figure 5: Simplified model of N-mass mechanical system during moving of n-th mass

It is obviously that n=2, 3… N-1. On the outer masses (first and last mass) acts the same propulsive force as on the inner masses. Before further analysis will be determine whether occurs movement of adjacent masses of n-th mass because of spring and damper forces.

A. Computational Analysis

For computational analysispurpose we further simplify as Spring-damper two masses system.

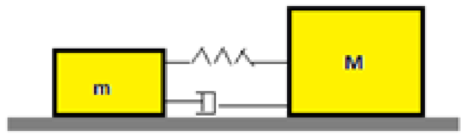

Figure 6. Simplified 2-mass mechanical system

The advantage of this model in comparison with model without passive bonds (springs and dampers) is that by suitable spring and damper coefficients can be motion kinematic parameters affected. The conditions of rectilinear motion of our model are that the mechanical system consists of N masses with the same weight m.

The equations of motion can be written as follows:

$$m\frac{d^2x_m(t)}{dt^2} + b\ \frac{d(x_m - x_M)}{dt} + k(x_m - x_M) = F_p \ - F^1{}_{fc} \dots. (1)$$

$$M\frac{d^2x_M(t)}{dt^2} + b\ \frac{d(x_M - X_m)}{dt} + k(x_M - x_m) = -F_p \ + F^2{}_{fc} \dots. (2)$$

Where x_m, x_M, m, b, k, F_p and F_{fc} are displacement of moving mass, displacement of static mass, weight of moving mass, coefficient of damper, stiffness of spring, propulsive force and Coulomb friction force, respectively.

Taking Laplace transform of both equations,

$$ms^2x_m(s) + bsx_m(s) - bsx_M(s) + kx_m(s) - kx_M(s) = F_p(s) - F^1{}_{fc}(s) \dots. (3)$$

$$Ms^2x_M(s) + bsx_M(s) - bsx_m(s) + kx_M(s) - kx_m(s) = -F_p(s) + F^2{}_{fc}(s) \dots. (4)$$

B. Analysis of nth moving mass

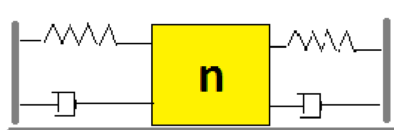

Figure 7. Simplified model of nth moving mass

C. ISO 8608 random surface

The ISO 8608 [7] describes the methodologies to be used for the generation of the road surface profile, by implementing two different procedures from data measured on site.

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The first provides a description of the road roughness profile through the calculation of the PSD (Power Spectral Density) of vertical displacements G_d, both as a function of spatial frequency n (n =Ω/2π cycles/m) and of angular spatial frequency Ω. In practice, on ordinate both G_d (n) and G_d (Ω) are plotted in function of n and Ω with log-log scale.

The second procedure provides the calculation of the PSD of the accelerations G_a (n) and G_a (Ω) of the profile in terms of slope variation of the road surface per unit of covered distance. The passage from the first to the second method is immediate, because the PSD of vertical displacements G_d and the PSD of accelerations G_a are linked by the following equations:

$$G_a(n) = (2\pi n)^4 . G_d(n)$$

$$G_a(\Omega) = \Omega^4 . G_d(\Omega)$$

The identification of the class of a real roughness profile measured on site is assessed by calculating the Power Spectral Density of the real profile in correspondence of n_0 and Ω_0, and then comparing it with those appearing in ISO Standard for the various classes.

In simulations, the ISO 8608 provides that the roughness profile of the road surface can be defined using the equations:

$$G_d(n) = G_d(n_o)\left(\frac{n}{n_o}\right)^{-2}$$

$$G_d(\Omega) = G_d(\Omega_o)\left(\frac{\Omega}{\Omega_o}\right)^{-2}$$

where the values of $G_d(n_0)$ and $G_d(\Omega_0)$ must be derived from Table 1 on the basis of the considered road class.

Table I

ISO8608 values of Gd (n0) and Gd (Ω0)

Road class	$G_d(n_0)$ $(10^{-6}$ m$^3)$		$G_d(\Omega_0)$ $(10^{-6}$ m$^3)$	
	Lower limit	Upper limit	Lower limit	Upper limit
A	–	32	–	2
B	32	128	2	8
C	128	512	8	32
D	512	2048	32	128
E	2048	8192	128	512
F	8192	32768	512	2048
G	32768	131072	2048	8192
H	131072	–	8192	–
	n_0=0.1 cycles/m		Ω_0=1 rad/m	

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D. Simulation results

Simulation results using MATLAB are shown from Figures 8-13

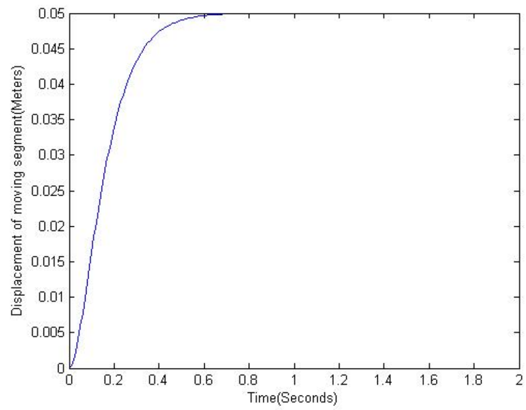

Figure 8. Displacement of the moving mass

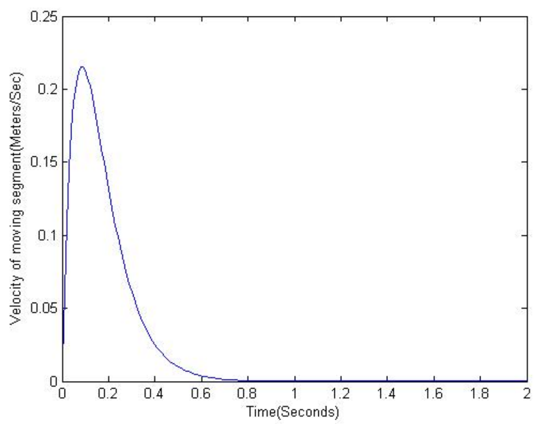

Figure 9. Velocity of the moving mass

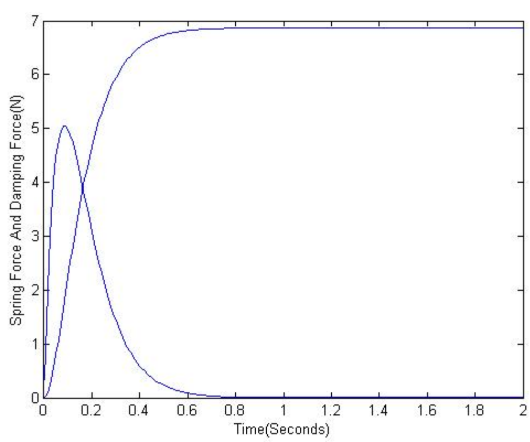

Figure 10. Spring and damper forces

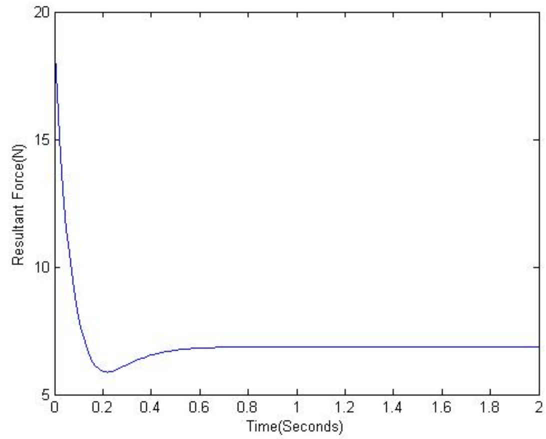

Figure 11. Resultant force affecting the mass

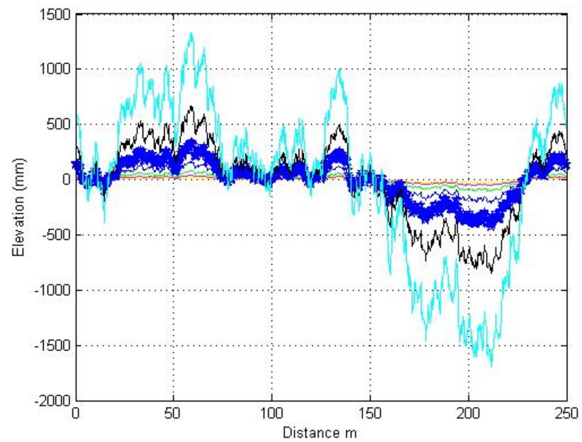

Figure 12. Random road surface

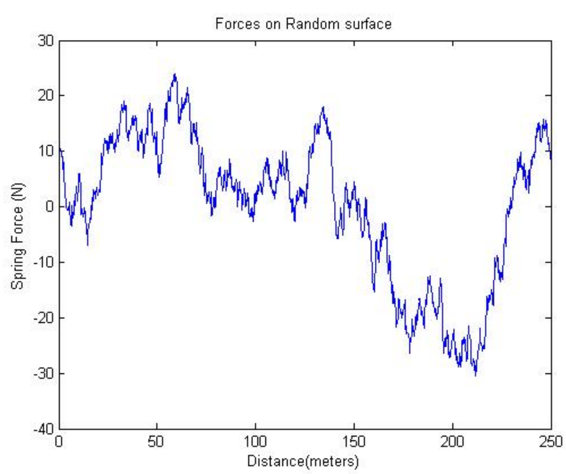

Figure 13. Behavior of rectilinear snake on random road surface

III. CONCLUSION

In this paper the snake rectilinear motion was investigated. Snake body was replaced by identical masses which represent the segments of snake robot. In this paper the snake rectilinear motion mathematical model is established and the displacement and velocity of n^{th} moving mass is derived. Computational analysis of snake rectilinear motion was done for ISO 8608 random surface using Matlab and the results are shown above.

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