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SNAKE-LIKE ROBOT RECTILINEAR MOTION ANALYSIS

Urgency of the research. *Some animal locomotion mechanisms are often used for robot designing because of their appropriate properties for some kinds of environments. A snake has excellent skeletal structure which provides it advantageous properties for reaching places where other kinds of mechanisms cannot move and operate.*

Target setting. *A biologically snake by mathematically way is described. The properties of N-mass mechanical system by increasing number of masses are changed with the certain regularity which in this paper is determined.*

Actual scientific researches and issues analysis. *Only a few previous decades the researchers and the designers started to copy the animal motion to the mechanisms. The principal motivations of the snake locomotion are the environments where the traditional machines are not applicable due their dimensions or shapes and where the accessories like the wheels or the legs fail.*

Uninvestigated parts of general matters defining. *The rapid development of robotics and technologies offers large spectrum of a robotic devices use for hard reach areas or man danger zone. Some animal locomotion mechanisms are often use for robot designing because of their appropriate properties for some kinds of environmetns.*

The research objective. *Within this research one of four basic snake gaits is analysed.*

The statement of basic materials. *There exist various kinds of rectilinear motion models, for example models with masses, dampers and springs. In this study we will deal only with the mass model.*

Conclusions. *The paper also deals with the force effects on i-th moving mass of system and based on this the average velocity of the system is derived. In the conclusion the optimal number of masses N is established in order to the average velocity could be maximum.*

Keywords: *N-mass system; robot; snake.*
Fig.: 6. References: 6.

Introduction. Some animal locomotion mechanisms are often use for robot designing because of their appropriate properties for some kinds of environmetns. A snake have excellent skeletal structure which provides it advantageous properties for reaching places where other kinds of mechanisms cannot move and operate. Moreover, snake motion is very stable because during its motion it has most 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. However there are some cases which in the practical level are used. For example Israel army developed snake-like robot which for survey purposes is used as we can see on the Fig. 1.

A rectilinear motion is the second basic motion of snakes and absolutely differs from other ways of the snake motion. The rectilinear motion is specific for the snakes with large body disabling them lateral undulation motion. This type of motion is slower then other ones. During the motion the abdominal scales are alternately smoothly lifting up from the surface and drawing forward and then lowering down. The parts of the abdomen skin are drawing forward and so the abdominal scales are joining in the bunch. This part of the body is then pushing down and the sides of the abdomen go down on the surface. Although this type of motion is not very effective but its properties are appropriate especially for narrow spaces [1, 2, 4].

Fig. 1. The military snake robot [5]

Mathematical model. There exist the various kinds of mathematical models of a snake-like robot motion depending on gait pattern. If a robot use passive wheels there is sufficient use only kinematic model (mostly within lateral undulation motion), however robot which doesn´t use any equipment (active or passive wheels, tracks etc.) for motion have to be described by dynamic model. The snake-like robots with wheels reduce friction forces acting between robot and surface however within robots without wheels friction forces play an important role during a motion. Generally there are used two kinds of friction models such as Coulomb´s friction model and viscous friction model. There exist various kinds of rectilinear motion models, for example models with masses, dampers and springs. In this study we will deal only with the mass model. If we want to analyze a snake body we have to see its biologically body as the series of N homogeneous consecutive elements where each element performs some activity as we can see on the Fig. 2.

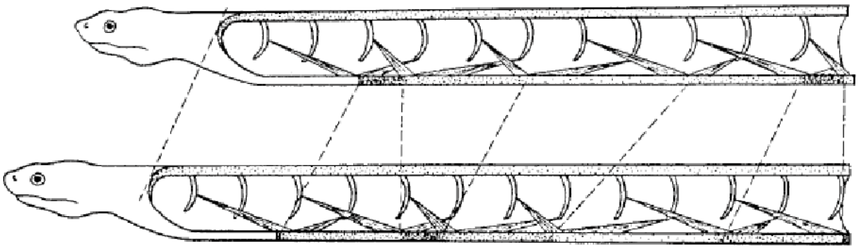

Fig. 2. The Anatomy of Rectilinear motion [6]

Some body parts are in static contact with the surface while other are shortened or lengthened. Combination of these activities the rectilinear motion is performed. In the Fig. 3 a simplified model of a snake is shown. The snake rectilinear motion on this model will be analyzed [3].

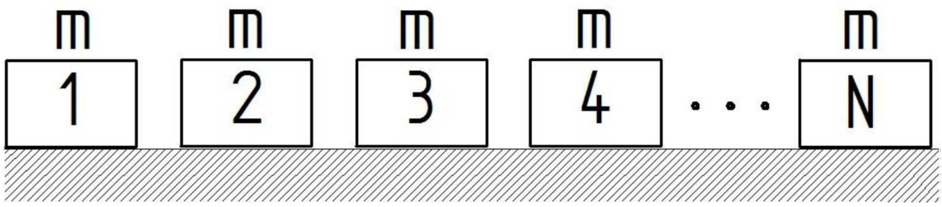

Fig. 3. Simplified model of a snake

Before we derive mechanical system average velocity we will analyze mechanical system consisting of three and four masses. Each system will be consists from N phases and each phase into two sections is divided. During the first section i-th mass to the (i+1)-th mass is attracted and during the second section i-th mass is slowed down.

Three-mass mechanical system. The motion sequence of 3-mass system is:

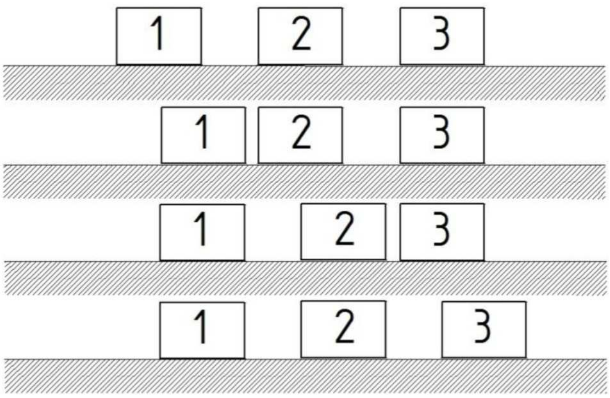

Fig. 4. The motion sequence of a three-mass system

The motion of this mechanical system consists of three phases. During the first phase the mass 1 will be attracted to the mass 2 while masses 2 and 3 stay at rest (it means that actuator between mass 2 and 3 maintains their relative position and they behave as one mass). The propulsive force is maximal force which can affects on masses 2 and 3 so that these masses can stay at rest. Forces of dry friction, obeying Coulomb´s law, act between the masses and the surface. In this case Coulomb´s friction force depends on direction of velocity of moving mass and its weight m.

$$F_p = 2kgm$$

The first phase duration is:

$$t_{cl}^{(3masses)} = \sqrt{\frac{4s}{kg}}$$

Where k is friction coefficient (system behaves with isotropic characteristics), s is maximum possible extent between two masses and g is gravitational acceleration. During the second phase the mass 2 is attracted to the mass 3 while masses 1 and 3 stay at rest. The propulsive forces between masses 1 and 2 and between masses 2 and 3 are:

$$F_{p1} = F_{p2} = kgm$$

The second phase duration is:

$$t_{c2}^{(3masses)} = \sqrt{\frac{4s}{kg}}$$

During the last phase the mass 3 is pushed from mass 2 while masses 1 and 2 stay at rest. The propulsive force is:

$$F_p = 2kgm$$

The third phase duration is:

$$t_{c3}^{(3masses)} = \sqrt{\frac{4s}{kg}}$$

We can see that in each moment of the motion the same total force on each moving mass is affecting. The average velocity of the 3-mass system is:

$$\upsilon_A = \frac{1}{6}\sqrt{kgs}$$

N-mass mechanical system. Based on previous findings we can derive the average velocity of N-mass mechanical system.

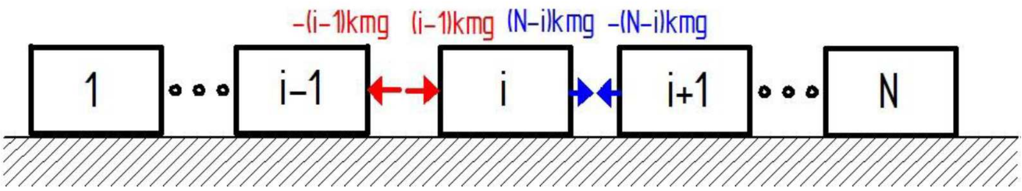

Fig. 5. N-mass mechanical system

According to the Fig. 5 N-mass mechanical system we can describe two propulsive forces affecting i-th moving mass in arbitrary time as:

$$F_{p1}^{(i)} = (i-1)kgm$$

$$F_{p2}^{(i)} = (N-1)kgm$$

Where i=2, 3, ..., N-1. For ending masses the propulsive force is:

$$F_p^{(1,N)} = (N-1)kgm$$

Total force which affects i-th moving mass is:

$$F_T^{(i)} = (N-2)kgm$$

Based on previous equations we can derive relation of the average velocity of N-mass system.

$$\upsilon_A^{(N)} = \frac{1}{N\xi}\sqrt{kgs}$$

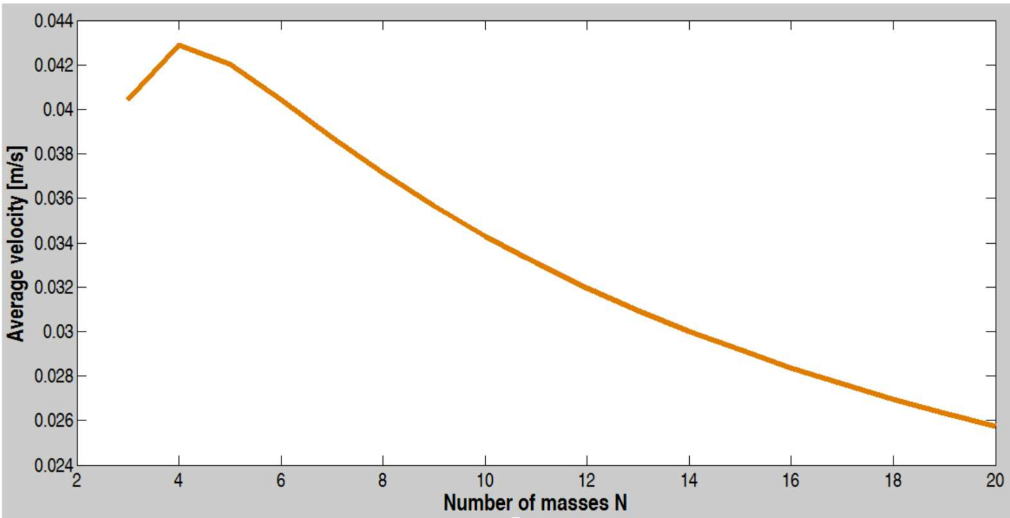

Fig. 6. The average velocity depending on number of masses N

Determination of optimal masses number we can obtain by determination of local extremum by derivation according to masses number N. The mechanical system will have the maximum velocity when N=4.

Conclusion. Only a few previous decades the researchers and the designers started to copy the animal motion to the mechanisms. The principal motivations of the snake locomotion are the environments where the traditional machines are not applicable due their dimensions or shapes and where the accessories like the wheels or the legs fail. Within this research one of four basic snake gaits is analyzed. A biologically snake by mathematically understandable way is described. The properties of N-mass mechanical system by increasing number of masses are changed with the certain regularity which in this paper is determined. The paper also deals with the force effects on i-th moving mass of system and based on this the average velocity of the system is derived. In the conclusion the optimal number of masses N is established in order to the average velocity could be maximum.

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АНАЛІЗ ПРЯМОЛІНІЙНОГО РУХУ ЗМІЄПОДІБНОГО РОБОТА

Актуальність теми дослідження. *Деякі механізми пересування тварин часто використовуються для конструювання роботів завдяки деяким їх властивостям, що підходять для певних видів навколишнього середовища. Змія має відмінну структуру скелета, що надає їй переваги для досягнення тих місць, де інші види механізмів не можуть рухатися та функціонувати.*

Постановка проблеми. *Математично описана біологічна змія. Властивості механічної системи з N-масами за рахунок збільшення кількості мас змінюються за певною закономірністю, яка визначається в даній роботі.*

Аналіз останніх досліджень і публікацій. *Лише протягом попередніх десятиліть дослідники та дизайнери почали відтворювати рух тварин у механізмах. Головною перевагою використання змієподібного переміщення є такі середовища, в яких традиційні машини не можуть бути застосовні через їх форму чи розміри, і де не можуть працювати пристрої на колесах чи ніжках.*

Виділення недосліджених частин загальної проблеми. *Швидкий розвиток робототехніки та технологій пропонує широкий спектр використання роботизованих пристроїв у важкодоступних місцях або небезпечній зоні для людини. Деякі механізми пересування тварин часто використовуються для проектування роботів через їх відповідні властивості для деяких видів навколишнього середовища.*

Постановка завдання. *У рамках цього дослідження проаналізовано один з чотирьох основних зміїних рухів.*

Виклад основного матеріалу. *Існують різні види прямолінійних моделей руху, наприклад, моделі з масами, демпферами та пружинами. У цьому дослідженні розглядається лише масова модель.*

Висновки відповідно до статті. *У статті розглядається вплив сили на i-ту рухому масу системи і на основі цього визначається середня швидкість системи. У підсумку встановлюється оптимальна кількість мас N для того, щоб середня швидкість могла досягати максимальних значень.*

Ключові слова: *N-масова система; робот; змія.*

Рис.: 6. Бібл.: 6.

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