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Energy Efficient Legged Robots: a Review

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ABSTRACT

Legged robots can easily adapt to irregular terrain and when compared to wheeled or robots on track they have the potential to transverse certain type of terrain in a more efficient and stable manner. Legged locomotion is useful in providing better mobility in irregular landscapes. However the locomotion capabilities are often constrained by the limited range of gaits and the associated energy efficiency. This paper gives some details on growing impact of legged robots and the challenges and opportunity faced in extending the application of energy efficient legged robot system beyond locomotion at the say time keeping the gait cycles of their biological counterpart.

KEYWORDS : Legged Robots, locomotion.

I. Introduction

Technology is evolving and its applications are ever widening. One of the main focuses is to help mankind and increase the quality of life. Robots come in handy and it is widely used in mass production environments moving workers away from dirty, dangerous and repetitive jobs. Even though mass production is the primary application area of robot, but researchers are working to deploy solution for real world environments. In parallel researchers are working to deploy robots in surgical areas and we also can find robots in educational field. It can be seen that that robots are moving from traditional industrial and service application to new areas with relatively unstructured environment to perform task that needs robustness, adaptability and advanced communication abilities in order to deal with unexpected situations.To handle complex task which needs higher degree of adaptability, robustness and extendibility of applications, robots developers are adopting reconfigurations principles in their design. The challenge is how to redesign the current available robots so that it application can be extended other than its intended use in an energy efficient manner. The objective of this study is to explore energy efficient mechanism to be applied in reconfiguration design of legged robots to realize applications beyond locomotion.

II. Legged ROBOTS: an Overview

In recent years, the research and development into legged robot is gaining significant momentum from the worldwide robotics research community witnessed by grandeur initiatives from universities, companies and governments.Some outstanding research projects about legged robots that have got lots of attentions such as Asimo from Honda, Bigdog and Wildcat from Boston dynamics, etc as shown in figure 1. These robots, for example, can be deployed in office building for helping people in carrying things, or working in dangerous, hazardous places where people cannot access into.

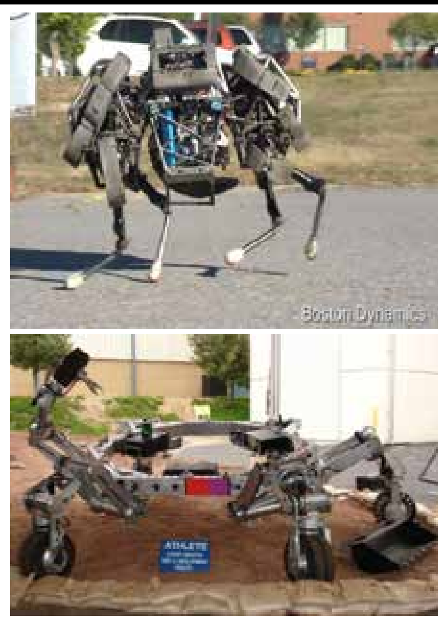

Figure 1.Various types of legged robot. From left to right: Asimo of Honda; Wildcat of Boston Dynamics; Athlete of NASA.

Most legged robot designs are inspired from and mimic the structures and functions of natural systems. Moreover legged robots are preferred choice for researches when locomotion over uneven terrain is involved. Xi et al. [1] has done a prototype development and gait planning of biologically inspired multi-leggedcrablike robot. However, such kind of legged robots often have the ability to move through irregular, abrupt terrains and show their significant versatility and manoeuvrability over wheeled robots, which can only move on prepared land. When compared to wheeled or robots on track, legged robots have potential to transverse certain type of terrain in a more efficient and stable manner.Sebastian et al in [2] has presenteda bio inspiredsix leg energy efficient robot suitable for space climbing. In [3], Federico has described how a horse walking gait can be mapped to that of aquadruped robot to generate natural locomotion. For such kind of legged robots, the contact with ground is discontinuous which enables them to select footholds to avoid obstacles and cause less damage to manoeuvre in cluttered and tight environments. However, any direct realization of natural locomotion methods on an artificial legged robot is really difficult pertaining to: complexity in mechanical structure, many degrees of freedom on one leg for smooth movement, complicated control algorithm, low payload to machine load ratio and energy consuming problem. Researchers are studying various approaches to propose energy efficient walking methods that could mimic gait cycle of a biological species.

III. ENERGY EFFICIENT LEGGED ROBOTS

Numerous efforts have been dedicate to develop energy efficient legged robots. To achieve energy efficiency researches have chosen various methods and technologies, like one degree of freedom, under actuated system, smart battery management and control approach. Implementing energy efficient leg behaviour is a challenging task. The major obstacle is energy requirement and the control complexity. In [4]an energy efficient biologically inspired biped based on the influence of monoarticular structure has been designed. In [5] an energy consumption model has been derived for statically stable wave-crab gaits based on minimization of norm of feet forces and minimization of norm of joint torques have been developed. Sanz-Meodio et al [6] presents a set of rules towards improving energy efficiency in statically stable walking robots extracted to careful dynamic simulation and analysis of two legged, mammal and insect configurations for a hexapod robotic platform. Gonzalez de Santos et al [7] applies minimization criteria for optimizing energy consumption in a hexapod robot over every half a locomotion cycle especially while walking on uneven terrains.

Typically, each leg of a legged robot is designed with three to six actuators to control the movement of each leg. This helps the leg move flexibly and produces numerous gaits. Though, the use of many actuators in this case requires a more complex controller and more energy to drive. Therefore, the study of a mechanism which can meet the requirements for both flexible movement and energy saving with a simple control algorithm is essential now. Traditional way is to add more actuators for different gaits. With addition of actuators the complexity of controlling the legged robots increases along with energy consumed.

Since the beginning of the land transportation technology, numerous walking machines have been conceived and designed as an alternative to wheel vehicles because of their potential advantages in rough terrain. These benefits include, for example, higher speed, better fuel economy, greater mobility, better isolation from terrain irregularities, and less environmental damage. A complete survey of the walking machines developed in the last decades can be found in [8]; where it is shown that different kinds of leg mechanisms have been proposed, systems that span from open planar kinematic chains to parallel architectures.Leg mechanism based on a closed planar kinematic chain of one degree-of-freedom are been used in the construction of legged robots. This class of leg mechanisms has been selected in our survey because of its energy efficiency and simplicity of gait control.

An unconventional approach based on one degree of freedom was presented by Theo Jansen, and Klann that requires actuation at only a single joint to realize walking involving multiple legs through mapping of internal cyclic gaits into elliptical ones as shown in figure 2. Various design aspects of these mechanismshave been studied by number of researchers to develop energy efficient walking systems. In more recent times, Theo Jansen and Klann Mechanism based on two one degree-of-freedom leg linkages have stood out for energy efficiency. Both are similar in that they operate in a single plane, provide a constant axle height, use only pivot joints, a rotating crank for input, and can easily be scaled in size. The Jansen linkage model as shown in figure 3 corresponds to an eight-bar kinematic chain; it was created by Theo Jansen during his works of fusion of art and engineering, the history of the linkage development and invention is described in [9].The Klann mechanism, conceived by the Mechanical Engineer Joe Klann in 1994, is a Stephenson type III kinematic chain (a five-bar linkage attached to a frame) designed from the four-bar Burmester linkage [10] as shown in Fig 4.

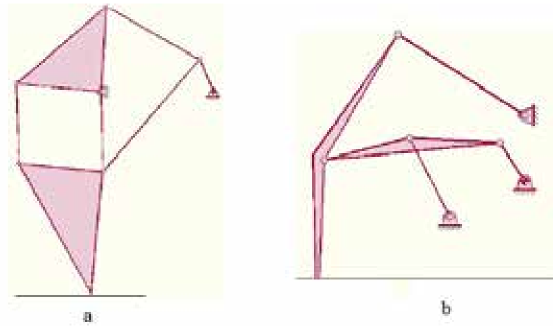

Figure 2.Jansen (a) and Klann (b) mechanisms.

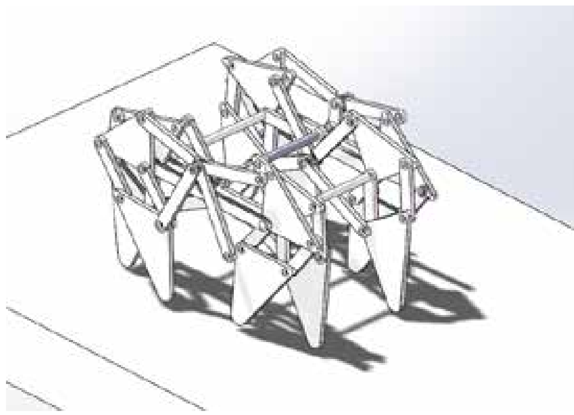

Figure3.Walking model based on Theo Jansen Mechanism

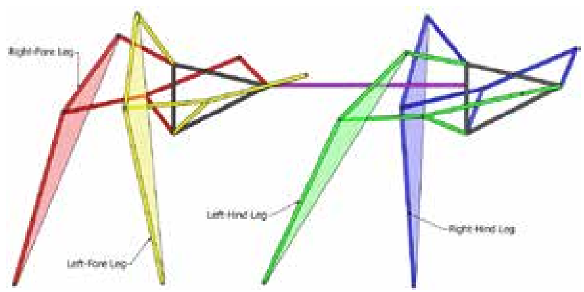

Figure 4. Platform based on Klann Mechanism

IV. Reconfigurable Design approach

In nature, not all legged species have the same locomotion. Individuals from mammals, reptiles to insects have different walking gaits and can only swap their gaits within a limited number constrained by their species morphology. Similarly, a robot that has a fixed structure of movement mechanism faces issues related to constrained set of gaits that it can produce. The energy efficient single degree of freedom based Theo Jansen and Klann Mechanism faces this bottle neck where different gaits cycles are needed to traverse more than one terrain.

Numerous research efforts have been dedicated to this end involving varied design strategies. One such design concept is that of interconnecting many small, simple and fewer degree of freedom robots to create a new, more functional structure. Those research presented in [11], [12] and [13] which is about modular self-reconfigurable robots provide small-scale robot blocks with the ability to connect with each other that possess a high level of autonomy and versatility in function. Self-reconfigurable systems are able to self-adapt to the external environment by changing configurations, as well as self-repair through replacement of disabled parts with spare modules. However, such an approach results in increasing difficulty in control algorithm when more and more units are connected with each other. Another design approach in the literature achieves gait variations via parametric changes of leg structure [14], [15], [16] and [17]. In figure 5 Klann based reconfigurable design capable to generating various gaits based on parametric change is shown.

Applying parametric changes to energy efficient one degree of freedom based Theo Jansen and Klann mechanism opens bottle neck to generate many usable gaits. Various gaits to traverse more than one terrain can be generated based on parametric changes. We hypothesize that the research and development of reconfigurable Theo Jansen and Klann mechanism robot has high academic value and practical impact.

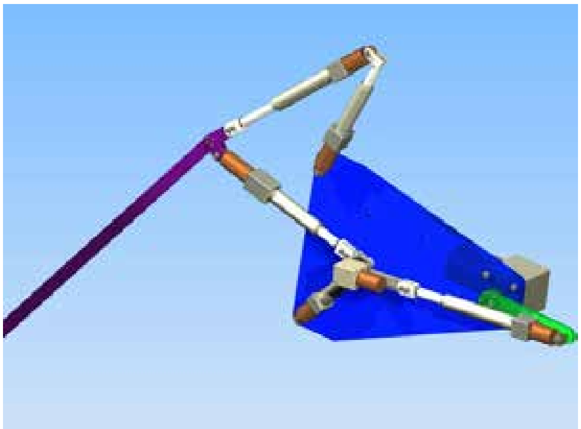

Figure 5. Reconfigurable leg length module (left) and Linear actuator (right)

By going for reconfigurable methods we can generate different gaits suitable for a given task without any changes in the number of actuator there by reducing the controller complexity and energy to drive actuators [18, 19].

V. CHALLENGES AND OPPORTUNITIES

Both Theo Jansen and Kalnn based reconfigurable mechanism produce gaits with one degree of freedom. This creates lot opportunity for legged robot to produce variable gaits to handle different task like climbing, rolling, crawling etc. They use least energy since one or two motors are activated during traverse. This solution can be extended to design solutions for legged walking chair, Wearable gait trainer for therapy etc. This platform can be a test bed to develop new algorithm and mechanism. The developed solutions present inherent challenges since linear motor introduces complexity and there is a tradeoff between simplicity and ease to control, due to the use of additional linear actuators for parametric changes. Fabrication, stability and synchronization control is quite complex. Based on wide range of gaits generated by reconfiguration useful gaits has to be identified. Autonomous reconfiguration based on terrain identification needs to be robust and stable.

VI. CONCLUSION

The paper analysis the need for developing energy efficient legged robots, which can extend legged robot applicationsbeyond locomotion. By applying reconfiguration principle to the existing energy efficient Theo Jansen and Klann Mechanism, useable gaits that take inspiration from biology can be generated. We hope that by extending the application areas of these energy efficient mechanisms will open new opportunities for legged robots in practical applications.

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