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Overview of Different Techniques Utilized in Designing of a Legged Robot

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Abstract

This paper focuses on the various techniques which are implemented to design a small scale legged robot. It specifies various parameters which play a vital role for designing of robot. It also provides the basic level analysis method which can be used to deal with calculation of force, generation of foot profile, calculating dimension of linkages and different method to help the robot to navigate across rough terrains using sensors and various other algorithm or programs, which instantly optimizes the foot profile of the robot to overcome any obstacle

Keywords: Jerk Reduction, Link Optimization, Walking Robot

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1. Introduction

For making the robots more efficient that previous one it is beneficial to use legs instead of wheels or rollers. Various mechanisms are available for actuating the leg assembly as per command of operator. Names and the structure can be varied by using different no of legs like 4 legged robot is called Quadra pad, six legged is called Hexapod and 8 legged is called as Octopod robot[1]. All these structures are having higher degree of freedom, better accuracy in working and all terrain mobility. As seen in previous robots having less ground clearance, they are not able to overcome many of the obstacles around them, but in case of legged robots the availability of higher ground clearance enables robot to conquer any difficulty as per required. One of the mechanisms used is Klann Mechanism which is most suitable for the legged robots as it has very simple structure[2]. The mechanism provides better stability and balance to the body if optimized properly. The out thus obtained can be redeveloped as per required shape and size.

Based on the type of application the control of legged robot may or may not depend upon microprocessor. Force transmission is depending upon the number of legs of robot. Designing of legs is crucial for better performance of robot. Besides designing the robot, detailed analysis should be involved in understanding the mechanism and its behavior during the working. Legged robot works better on the sleeper and sloppy floor. Since it has point contact for a brief moment of time with the ground, the risk involved with the condition of terrain have no adverse effect on the gait of the legged robot. The range and height of the robot is fit for traversing through landscapes which are unfamiliar to wheels. The minimum degree of freedom of such mechanisms is at least 2 that are along the vertical and the translational axis. By varying the dimension of every link purposeful gait can be obtained.

Now-a-days due to various environmental issues, numerous disasters are arising and it is difficult for our current technologies to cope with it[3]. The possibilities for any wheeled robots to achieve this task are very slim, hence the legged robots created curiosity for disaster management. The potential of a legged mechanism to navigate irregular terrains shows more promise, in rescuing people from disaster sites. In defense sector, soldiers have to carry twice their weight so such legged robots can provide support. Certain applications are underway such as utilizing a legged robot as a wireless robot which can lead the troupe. Having better weight distribution, it can be used for waste material handling on industrial floor. It can also be used as transporting media from source to its processing area.

According to statistics, 23% of worldly population comprises of disabled people which find doing certain activities like hacking, trekking, climbing etc. difficult[4]. To enable them to overcome such difficulties special purpose robots can designed, which can help them to experience the tasks. Biological gaits are analyzed for robot to perform various tasks as described above[5].

Through observations of animals in nature, it is clear that legs are more reliable for overcoming the terrains. Through advances in technology, underwater sea exploration has become possible but traversing through irregular, unstructured terrain is a problem. To overcome these difficulties the robots are equipped with legs (kinematic linkages)[6]. The robots are provided with

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many sensors to detect the terrain and simulate the gait which is essential for overcoming the obstacles. These underwater robots are creating interest for researchers to go deeper in this field for exploring depths. Similar advancement has been made in aerospace[7]. In order to explore the surfaces of planets, various programs involving legged vehicles have proven to be better than wheeled robots. Precision and stability of such robots has enabled various operations which require rigid structure and posture.

2. Necessity of Legged Robots

1. Legged robots can traverse on any type of surfaces which is unable for robots with wheels. Also, wheels are designed to work on prepared surfaces like smooth surfaces, roads, rails. Where in case of legged robot it is not required.
2. Legged robots can overcome any type obstacles whereas wheels need to somehow travel over it, or had to choose a different path for travelling.
3. Wheels require a continuous path to travel whereas legs can step over isolated paths and move on. For example, in an earthquake conditions the wheeled robot does not perform at many condition so legged robot come into picture and work efficiently.
4. Legged robots can avoid undesirable jamming in ditch which cannot be avoided in a wheeled robot
5. In a defense sector for many operations are performed where legged robots perform as weight carrier or armor carrier.

3. Literature Review

3.1 Optimization of Linkages

Optimizing the design of linkages by Utilization of sensors to enhance adaptively of the robot to overcome challenging land marks[1]. Interchangeability in mechanical design of the linkages results in flexibility and less maintenance of the robot[4]. By increment in number of links the weight distribution and force transmission is improved. Detail discussion of profile generation at every stage of crank revolution[6]. Relation between the rocker and ground point contact, duration of contact, time of engage-mint and disengagement is analyzed[7]. For monopod operation hopping principle is used which appears in the form of pogo stick used as leg for motion[17]. Various mechanisms such as Klann and Theo Jansen linkages have been utilized for optimization of linkages[20].

3.2 Reduction of Jerk

Reduction of jerk in robot, due to impact of leg while operation by utilization of spiral spring at the end of the rocker[1]. Actuators are driven by time chain controlled by integrated circuitry and microprocessors. Actuation is also use for jerk and vibration elimination by providing a ramp starts and ramp stop using a high torque stepper motor[3]. Dynamic controls of vivid gaits are produced by advanced electrical circuitry. Better stability is achieved by increasing the number of appendages and providing a singular plane thickness (avoid tipping) [13].

3.3 Methods to Navigate the Robot

Use of fault detection and diagnosis method (FDD Method) fault tolerant gait for adaptive locomotion. FDD method deals with failure of mechanism at uneven terrains and helps the robot to map the terrain and choose a particular gait[5]. Advancement in field of legged robot using sensors and actuators[10] and wireless transmission for navigation without risk of life by isolating the operator from the machine[11]. Whiskers as a sensory detector for navigating the terrain. Utilization of sensors introduces closed loop system for detection of obstacles and optimizing the gait required to navigate. Use of advance algorithm of probes to sense and trace ground irregularities and select a gait which is suitable to traverse the ground[14]. The algorithm can produce bilaterally symmetric design which shows more promise on irregular surface[15]. Use of Mobile Phones to Control the robot and computer software to formulate and execute the gait information[16]. Passive dynamic walking is one of the techniques used to overcome navigation in biped walking.

4. Methods used for Estimating Various Parameters

4.1 To obtain the desired foot profile the method utilized are

1. Two gear method (Bermester curves)

Initially, the desired profile is constructed, and then the alignment and orientation of the kinematic linkage is fixed on the basis of the profile required using 2-Gear system. Fig1shows computer generated profile using 2-gear method. In this system, the center of the gear and the crank are connect and a link is produced, the end point of the larger link which traces the profile is made to follow the curve and the gear position are varied accordingly. The new position of the gear is provided a third link (centre to centre distance of gear) which dictates the motion of the first two linkages. Based on the profile this procedure is repeated for every new position of the gear obtained.

2. Iterative method (Trial and error)

This method is generally used to obtain a desired profile. The length of the links, no of the linkages, the angle and orientation, thickness and the spacing between the links are few of the lot of variables to be considered. Fig 2 gives the iterative method using CAD software. A set of variable are predetermined and the remaining parameter are calculated by a simple technique till the profile is obtained. This method hold good if the set variables are carefully determined else can result in countless hours of work which is not advisable.

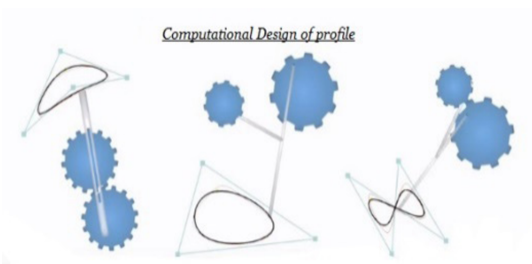

Figure 1. Computer generated profile using 2-gear method.

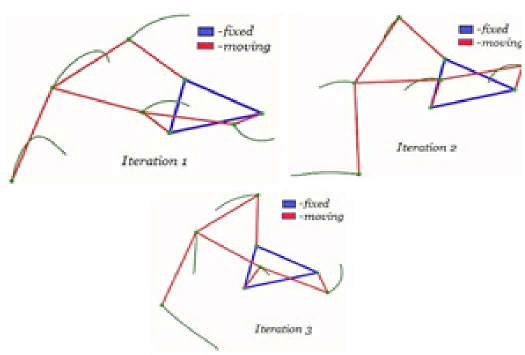

Figure 2. Iterative method using CAD software.

3. Forward and inverse kinematics method

Forward and inverse kinematics both involves using kinematic equations in order to determine the foot position of the robot and to find the joint of the leg. In forward kinematics, the joint positions, or angles of each joint, are known and the end effectors position can be calculated. Conversely, in inverse kinematics, the foot position is known and the related joint positions can be derived. Modeling the motion and positioning of a two link leg model is essential for the dynamics analysis of the robot as well as the gait animations. The two link leg models represent the position of the foot and are the joint angles of the hip and the knee, correspondingly, and denote the dimensions of the thigh and shank, respectively.

4.2 Method used to calculate dimension in linked mechanism are

1) Geometric ratios:

In this method, the length ratio of each corresponding link is calculated based on its point of rotation (ICR). By understanding the motion of one link with respect to another, its angular orientation can be noted with each position of the link. The dimensions of the links are deduced based on size of the entire body and the weight carrying capacity.

2) Iterative method (Trial and error):

In this method, a length of a particular link is predetermined and based on its other links are calculated. This method hold good if the set parameters are carefully determined.

4.3 Methods utilized to obtain various gaits

1) Time Chain:

By providing time chain to the crank, the angular position of the crank with respect to other crank can be set. By providing appropriate angular lag in between the cranks (Crank number is based on the number of the motors used), specific gaits of the foot can be obtained.

2) Arrangement of motors:

In case of motorized robot, by arranging the motors which perform a specific function that is either to move clockwise or anti-clockwise, a particular gait can be obtained. Illustrative: For a Quadra-pod, if each leg is controlled by a stepper motor then the motors with clockwise and counter-clockwise can be arranged such that the front left leg moves initially followed by the hind right leg then the front right leg moves followed with left hind leg. Such movement of leg is called a "walk". Similarly, different arrangement can provide different possible gaits.

3) Complex algorithm:

This is one of the advanced methods used till date. It utilizes programming the gait by carefully calculating the angular positioning of the leg with respect to crank or the pivot joint. Based on the type of system used to actuate the rocker (leg), a program is produce and fed to a microcontroller which governors the gait of the robot. Use of codes divides the operation of providing input to the system, analyzing it and generating the gait among the accessory devices. This eliminates overloading and permits smooth individual functioning of each component irrespective of the other. Algorithms also provide immediate response of the robot if the new obstacles arise. This degree of flexibility for gait optimization with every changing obstacle is high compared to any other form of gait generating method.

5. Analysis Techniques used

5.1 Force Analysis

First, mechanical analysis of a single leg was conducted before the quadruped robot was analyzed as a whole. Since all four legs are identical, the forces and torques present in one leg are similar in the other three legs. With the analysis for a single leg completed, mechanical analysis for the whole robot model was conducted. For each analysis, a FBD was drawn for the rigid body as a whole and its individual components were studied as shown in Fig 3.

Once the mechanical analysis of one leg can be determined, analysis of an assembly is conducted. From the modeling results of the single leg, the torques calculation in each hinge are made in terms of reaction forces applied at the tip and the kinematic variable of the legs and the known physical properties of the legs.

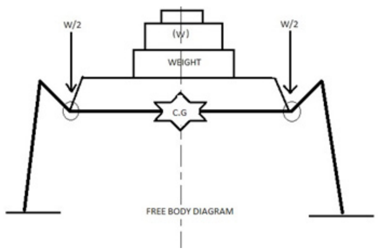

Figure 3. Free Body Diagram of skeleton of legged robot.

5.2 Instantaneous Centre of Rotation (ICR's) for Dimensional Analysis

The instantaneous center method of analyzing the motion in a mechanism is based upon the concept that any displacement of a body having motion in one plane, can be considered as a pure rotational motion of a rigid link as whole about some center, known as instantaneous center or virtual center of motion. The number of instantaneous centers in a considered kinematic chain is equal to number of combinations of two links:

$$N = \frac{n\,(n-1)}{2}, \quad n = Number\ \ of\ \ links$$

The Kennedy's Theorem states that if three bodies move relatively to each other, they have three instantaneous centers that lie on a straight line. When the two links are connected by a pin joint, the instantaneous center lies on the center of the pin.

Procedure to obtain center of rotation:

1. Determine the number of instantaneous centers.

Table 1. Comparison of various driving components

Parameter	Mechanisms	Actuators and Sensors	Stepper Motors	Combinations
A) Motions	Restricted due to Joints and fix points. [1,4,6,11,12,19]	Smooth due to simple structure. [1,16,18]	Accurate since the step is predetermined. [5,16]	Sooth and accurate.[1,19,20]
B) Degree of Freedom	Depend upon the structure and the number of joints, number of linkages and the plane of motion. [6,8,12]	Depends on the placement of the elements. Number of components may affect the degree of freedom. [3,16]	Depends on the placement as well as the constrained provided. [2,16]	Varies according to use of number of components. Depends on the placements of elements as required. [1,9,20]
C) Stability	Depends upon the structure and placement of mechanism. [4,11,19,20]	Number of joints affects the stability of actuator system. [2,16,18]	More the number of motors, better the stability. [5,18]	It has all the advantages in case of stability. [1,14,20]
D) Number of Inputs	Generally one. To increase the number of inputs the modifications made. [6]	Depend upon the motions required and the expected outcomes. [3,16]	Depend upon the motion of individual motors and the expected outcomes from systems. [5,12,16]	This system can have number of inputs controlled through one control centre.[3,14]
E) Gaits	Limited gaits can be obtained. [6,9,11,12,18]	More compared to mechanism systems. [15,18]	Various complex gaits can be obtained. [4,5,8,16]	Number of components affects the gait to be obtained. [8,9,11,15]
F) Sensitivity	Less sensitive to inputs. [6,19]	More sensible than mechanical components. [2,7,8,13,16]	Motors are more sensitive to inputs. [11-14]	Better sensitivity. [7,11,14,16]
G) Load Capacity	Generally, the load carrying capacity is less. [2]	Has better load carrying capacity since the losses are less. [15]	More load as compared. [11]	Better load carrying capacity. [14,15]
H) Force Transmission	Good force transmission. [9,12]	Better force transmission. [6,15]	Comparatively good force transmission. [14,12]	Most efficient force transmission. [15,18,20]
I) Efficiency	Depend upon the condition and number of components in system. [18,20]	More efficient in all aspects compared to mechanism systems. [4,16]	Efficiency depends upon the number of control points. [15,16]	It is most efficient system used in robotics. [14,15,18,20]

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2. Locate the fixed and permanent centers by inspection.
3. Locate the remaining neither fixed nor permanent centers by Kennedy's theorem(this is done by circle diagram)
4. On the circle diagram, join the points by solid lines to show that these centers are already found

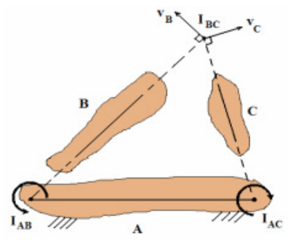

Figure 4. Instantaneous centre of rotation.

To find the other instantaneous centers, join the two corresponding points. The line joining them forms two adjacent triangles in the circle diagram. Instantaneous centre of rotation is shown in Fig 4.

5.3 Vibration Analysis

Most of the vibration arises when the rocker makes ground contact causing the impact to be transmitted through the body.

Formulating the characteristic equation of mechanism by carefully studying the motion, its displacement Y and Z and the relative relation between them,

$$m\ddot{x} + c\dot{x} + kx = c\dot{y} + ky$$

$$\ddot{x} + 2\zeta\,\omega_n\dot{x} + \omega_n^2 x = 2\zeta\,\omega_n\dot{y} + \omega_n^2 y$$

$$x(t) = Re[z(t)]y(t) = Y\cos(\omega t)w = Y\,Re(e^{-i\omega t})$$

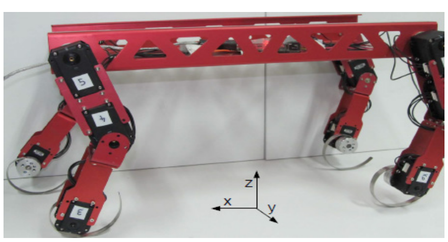

Figure 5. Dynarobin - a compliant quadruped robot design[1].

$$\ddot{z} + 2\zeta\omega_n\dot{z} + \omega_n^2 z = 2\zeta\omega_n\left(\frac{d(Ye^{-i\omega t})}{dt}\right) + \omega_n^2 Y e^{-i\omega t}$$

$$z(t) = Ze^{-i\omega t}$$

$$Z = \frac{\omega_n^2 + 2\zeta\omega\omega_n i}{-\omega^2 + \omega_n^2 + 2\zeta\omega\omega_n i}\ ; \qquad Y = \frac{1 + 2\zeta ri}{1 - r^2 + 2\zeta ri}$$

$$|H(\omega)| = \left|\frac{Z}{Y}\right| = \sqrt{\frac{1 + (2\zeta r)^2}{(1 - r^2)^2 + (2\zeta r)^2}}$$

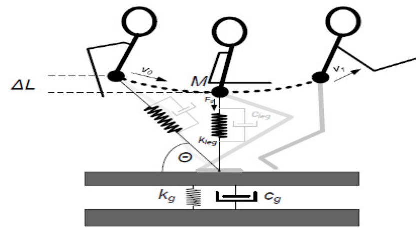

Figure 6. The SLIP model behavior[1].

Here, $H(\omega)$ represents the "Displacement Transmissibility" which tells how motion is transmitted from the base to the mass at various driving frequencies

By calculation of magnitude of base excitation appropriate damping system can be used such as Dynarobin, which utilize a spiral spring to reduce vibration during ground contact Fig 5.

6. Conclusion

This paper gives a brief idea about the various parameter involved in the designing of legged robot. Different techniques involved in analyzing the foot profile are studied and methods to obtain optimum gaits are derived. The paper reflects comparison between various components used as the driving mechanism of robot as shown in Table 1 and specifies best possible alternative for the same. Analysis techniques like force analysis, I.C.R, vibration analysis are few of the core methods for analysis of the legged robot. This paper highlights methods which are man the future

7. Future Scope

We hope that this paper provides basic clarification for future aspirants who aim at building a robot on small scale. By utilizing this knowledge with realization of these few amongst the many methods available, one can aim to create a prototype without being under the false impression of choosing a wrong methodology to make a legged robot, also a simple comparison between various driving source is provided to provoke the understanding of cost, time, energy, efficiency and reliability of various component while making a robot. Above mention techniques of analysis can help in creating a simple robot.

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Conflict of Interest:

Author of a Paper had no conflict neither financially nor academically.