Six Legged Terrain Adaptive Vehicle – A Report

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ABSTRACT

Manmade means of locomotion are based on wheels, while animals in nature use legs for locomotion. It is natural to think that animals have been forced to adopt an inferior legged locomotion scheme due to the inability of nature to create a continuously rotating joint. The advantage of rotating systems for transportation is primarily energetic; however, the maneuverability of wheeled vehicles becomes severely restricted in cluttered terrain. Almost half of the earth's terrain is inaccessible to wheeled vehicles. The scarcity of rotating systems in nature appears to be more due to the limited utility of such systems in natural terrain than due to the constraints intrinsic to biological systems (physiological problems of nutrient supply).

Over recent years, growing interest for developing legged robots and combination of innovative engineering with scientific observations on legged animals resulted in a number of artificial walking systems. In spite of the worldwide efforts of the last few decades, the development of mobile robots with legs is mostly restricted to laboratories. The performances of these machines are far inferior to those of legged animals.

Our project, SLTAV (a prototype) tries to overcome the difficulties faced by wheeled systems in maneuvering over rough terrains. It is a robot having six legs of two degrees of freedom each; this gives it ability to achieve smoother rides in rough and broken terrains by changing the effective length of its legs. We also aim to study various gaits being used in terrestrial locomotion by various animals. Initially we intend to use Alternating-tripod gait for its locomotion, then we will implement Follow-the-leader gait because of its better terrain adaptability.

WHEELED ROBOTS V/s LEGGED ROBOTS: NEED FOR THIS PROJECT

The main advantage of wheel locomotion is the ease with which it can be maneuvered. It is highly energy efficient and very high speeds can be achieved easily with the help of wheels. But it has got many disadvantages also, one being that it demands cluttered terrain, which means that more than 50% of earth's terrain is inaccessible to those machines.

Another important disadvantage is faced with large vertical step. It can be rectified by increasing the diameter of the wheel, but this may not be possible every time as there can be factors limiting wheel size. Also on soft ground a wheel is always climbing out of a rut of its own making; this wastes power. In an extreme case the wheel may just dig itself deeper until the vehicle stops permanently.

Legged locomotion on the other hand does not demand any special terrain. It also causes less damage to natural terrain as it leaves behind footprints of discrete steps. There are many advantages of legged locomotion over wheeled one:

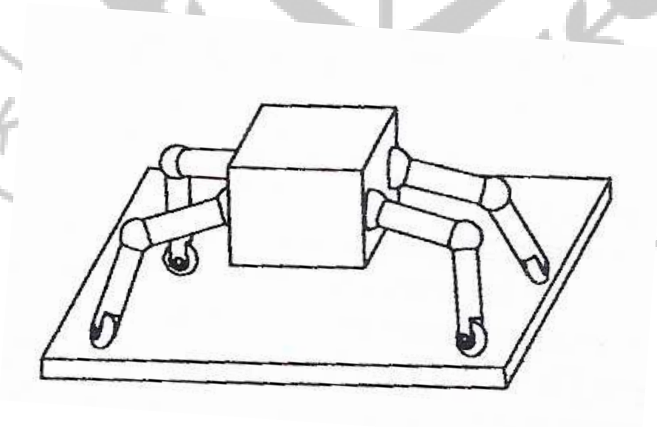
- One can step over obstacles and up and down stairs.
- Legged locomotion can even carry a vehicle over wide chasms or extremely broken ground.
- One can achieve a smooth ride on rough ground by varying the effective length of its legs to match the undulations of the ground.
- It can work efficiently on soft grounds, where wheeled machines fail.
- It causes less damage to the natural terrain.

DISADVANTAGES OF LEGGED LOCOMOTION

The fundamental problem with a leg is its limited steps, so that it must repeatedly be lifted and swung forward for another stroke. Therefore legged locomotion inevitably has cyclic characteristics in which each leg alternates between a support and propulsion stroke and a retraction or return stroke.

Also for achieving smooth ride at high speeds, more number of legs is required. More legs mean complex control, demanding higher computational abilities. Also *gaits* should vary with speed for every differential change in speed, which is again a bit difficult to achieve.

HYBRID ROBOT: A SOLUTION



Wheeled systems are easy to control and are highly efficient when it come to load carrying and high speed transport whereas legged machine can perform task efficiently in any type of terrain.
As the name suggests a *hybrid* robot is a robot which capitalizes on the advantages of both worlds. It contains legs, which help it in locomotion through rough terrains and soft grounds, for climbing over obstacles and stairs. While wheels help to achieve high speeds on smooth grounds.
This has been used in many robots so far. For e.g. In Mars Rover (Planetary rover), many military transport vehicles, etc. It can switch from legs to wheels and vice versa as the situation demands.

Why legs?

In his book (Bekker 1960) Bekker cited an average speed on rough and hard terrain of **5-10 mph** for tracked and **3-5 mph** for wheeled vehicles, while animals can reach a speed of the order of **35 mph** under similar conditions. Although it is true that tanks can achieve still higher speeds but at the cost of enormous power consumption & damage to terrain. Also for a plastic soil terrain with a 10 inch layer tracked vehicles consume **10 hp/ton**, wheeled ones consume **15 hp/ton**, while legged consume **7 hp/ton**. In another book (Bekker 1969), he used soil mechanics to explain the superior mobility of legged locomotion in loose soil.
The wheeled ones sink into soft soil whereas the legged can move across conveniently. Also, one can achieve a smoother ride on rough ground by varying the effective length of the legs to match the undulations of the ground.

Why hexapod?

- More number of legs means high stability at high speeds
- Redundancy: the ability to use fewer legs if some are damaged
- Various number of gaits can be implemented
- Vary height of the vehicle by varying the effective length of the legs

MECHANICAL DESIGN

The most important factor that governs the leg design of any walking machine is the number of degrees of freedom we want to give to each leg. In our case this was to be 2 DOF per leg. Based upon this the leg mechanism was decided.

POSSIBLE LEG MECHANISMS:

- Articulated leg Mechanisms
- Straight Line Mechanism
- Pantograph Mechanism
- Simple Four Bar Mechanism

Out of these following possibilities Articulated leg Mechanisms and Simple four bar mechanism were selected for further analysis.

Articulated Leg with Two DOF (Fixed Knee)

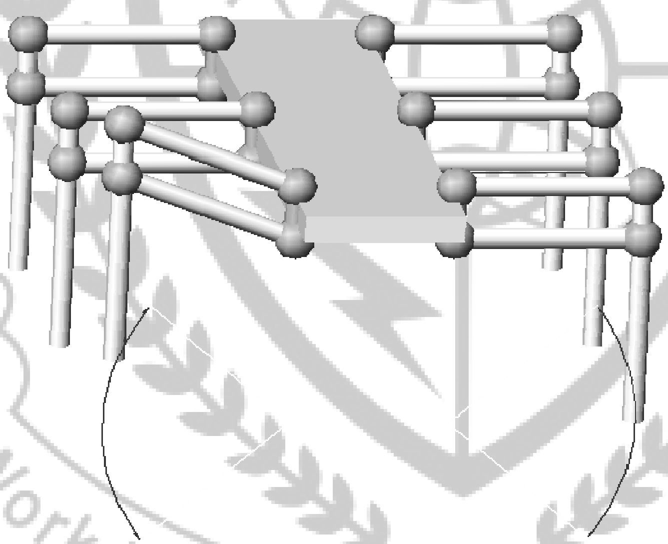
The advantages of this design

- Simplicity
- Low weight

The drawbacks of this design

- Feet need to slide when lifting a load
- Negative work involved

Four Bar Mechanism



Advantages of this design

- Legs move in less of an arc
- No Negative Work

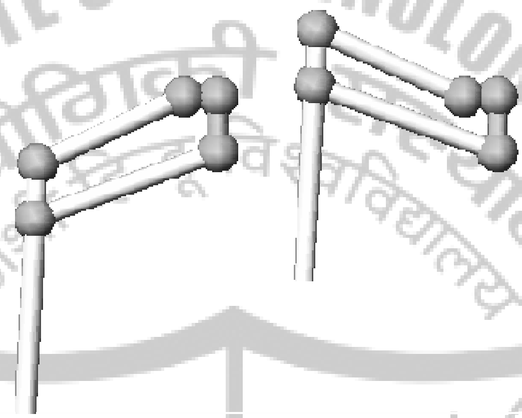
Drawbacks of this design

- More complexity than a fixed knee
- More weight

So a four bar mechanism was selected for the hip joint and a watts chain was selected for knee joint.

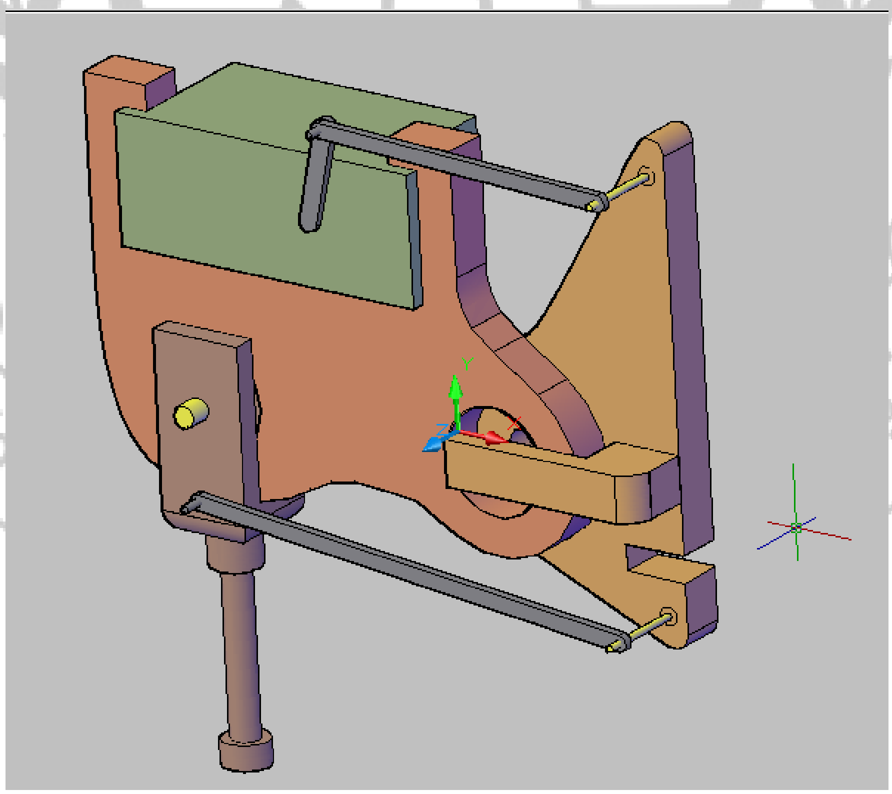
Deciding the Link Lengths

Joint Restriction: Leg range of motion was fixed to 40 degrees
(20^0 on both the sides of the mean position)



Based on the following assumptions link lengths were calculated and after a month long design process following designs were finally selected.

FINAL LEG ASSEMBLY



CONTROLLING THE SLTAV

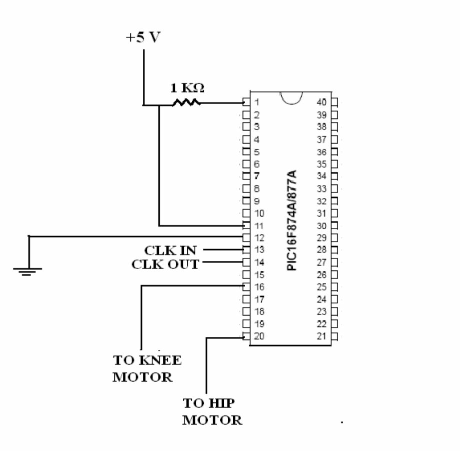
A leg is not a continuous locomotion element like a wheel. Therefore it must be lifted at the end of its effective stroke, returned, and placed to begin another support stroke. This creates a phasing problem, which is the problem described by the term “gait”. A gait of an articulated living creature or a walking machine is the *corporate motion of the legs*, which can be defined as the time and the location of the placing and lifting of each foot, coordinated with the *motion of the body* in its six degrees of freedom, in order to move the body from one place to another. Gaits describe and determine the speed, the direction of motion and the mobility of an animal or a walking machine.

Whenever a legged robot is in motion not all the legs will be on the ground, some are on the ground the remaining in air, preparing itself for another support phase. If the points of contact of all the legs are joined then the resulting polygon is called the *support pattern*. For a walking machine to be statically stable the projection of the centre of gravity must lie within the support pattern. As we have six legs here, we use *alternating tripod gait,* i.e. legs 1,3 & 5 work together as one set and legs 2,4 & 6 as another.

Components Used in the Circuitry

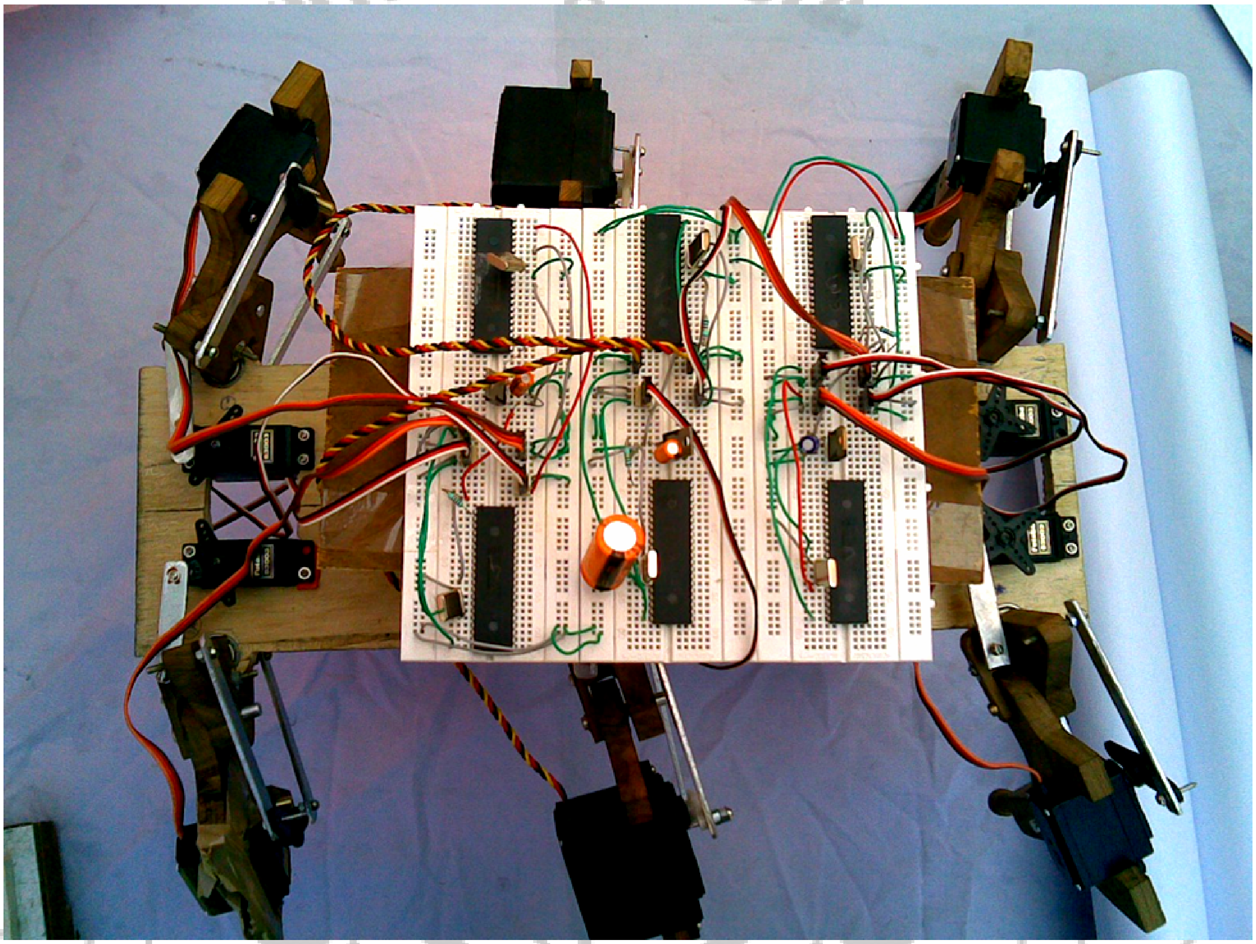
- PIC 16F877A
- Futaba S 3003
- Hi-Tech HS- 755
- Lotto MG-1055
- 1 KΩ Resistor
- 100 µF Capacitor
- 1000 µF Capacitor
- IC 7805
- 4 MHz Crystal Oscillator

As each leg has its own microcontroller therefore they all will have the following elementary circuit.



Additionally 1000 µF Capacitor is connect in parallel with main power supply to eliminate the ripples being generated and thus ensuring expected motion of the servo motors.

FINAL TOP VIEW OF THE MODEL



PROGRAMMING OF THE PIC 16F877A

As the servo motors need pulses to operate, we used a microcontroller to drive the two servo motors of a leg. The program required for the generation of the trajectory of the leg was fed into the microcontroller, so that the coordinated motion of the two motors results in the required trajectory. PicC compiler was used for programming of the microcontroller. The control signals for the two motors were generated from two separate pins(16 & 20). Program written in the compiler was basically to generate the required square waves at the two pins. Once the programs were compiled, the ".hex" file so generated was burnt into the microcontroller.

Applications

- **Urban Search & Rescue: Structural Collapse, fire, earthquake, railway accidents etc**. Clambering over the jagged piles of debris—powdered concrete and twisted steel—with the camera-carrying robots, lowering them into voids that are inaccessible to people, dogs, and other cameras involved in the search for bodies. Equipped with microphones to detect voices or other sounds of possible human presence within the ruins. Robots can also carry thermal cameras that can detect body heat; also cameras that search for colors distinctive from the gray dust that has. In most cases, rescue workers need to retrieve victims within about 48 hours. In any disaster, many hours pass before large numbers of human rescuers were able to begin searching for victims. This situation, illustrates why there is a need for search-and-rescue robots that are small, cheap, and light. Hundreds of them could be released immediately after a disaster in which the conditions are too dangerous for people and dogs to begin searching for victims. Current robots used for search and rescue not yet sophisticated enough to roam the rubble; some are too big and heavy to maneuver the terrain. Our robot is light and it can not only vary its height but can also maneuver in any kind of terrain that it encounters.
- **Clearing out mines**
  During warfare, such light weight robots can clear out the mine fields and make them accessible for Infantry divisions.
- **Mining**
  In remote and harsh environments robots will work either autonomously or via remote control, by operators located in more hospitable environments. Such robots are being developed by Australian engineers. In India one potential application is in Jaduguda Uranium mines, which is hazardous environment for human involvement due to the presence of dust etc.
- **Space Exploration**
  Hybrid robots have tremendous potential as far as space exploration is concerned as it has to encounter unknown terrain at the same time it has to be energetically efficient. Depending on the situation it can use Wheels for flat terrain and legs for stepped/rough terrain.
- **Defense**
  Such robots can boost the capabilities of the armed forces of our nation. Such robots are being used by many developed nations in their defense sector.

Accolades

- Winning Model of Modex - 08 (Technex-2008, Annual Technical Festival of IT-BHU.)
- One of the Major attractions at the Annual Management Expo-08 of Faculty of Management Studies, BHU.
- Presented at the Innovators Camp of "Technopreneur Promotion Program (TePP)", a Ministry of Science & Technology's attempt to provide a platform for commercially viable innovations.
- Appreciable response from media, an article on our model appeared in 4th September 2008 edition of Dainik Jagran. It described its various achievements, its applications and our future plans.
- Our model was also covered by various national news channels like Aaj Tak, India News, etc.

Our Future Plans

- Complete Automation with help of Sensors
- Implementation of Hybrid System
- Completely Terrain Adaptive System

We plan to make a **multipurpose terrain adaptive vehicle** which can have attachment/payload depending upon the demands of the consumer. It can also provide an energetically efficient means of locomotion for rough terrains.