

# Study of Theo Jansen Walking Machine

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**Abstract** –The Legged robots have comes to the researchers attention due to their abilities to overcome or deal with complex obstacles, high levels of mobility. On Earth surface the natural and manmade terrain vary from place to place. The availability of affordable and safe modes of transportation on the different types of terrain is costly and limited. This problem occurs due to the limitations of wheels which fail to deliver on rough, uneven and slippery surfaces. To solve this problem the new mechanisms of locomotion are still being researched even in the 21st century. One of the most successful mechanisms is Jansen's mechanism which is the sole work of Dutch scientist Theo Jansen. The working of this mechanism is very similar to that of the legs of animals. In future these autonomous creatures are able to live by their own, storing wind energy to move their PVC-made legs, detecting wet sands by the help of implanted nose feelers and escaping from danger by anchoring themselves to the ground. The main aim of this paper is to review the literature concerning the various applications of this mechanism in a developed or developing stage after it was invented in 1990. It is expected that this review would help researchers, engineers and artists to innovate even better mechanisms, make modifications to the existing mechanism or find new applications based on the existing mechanism.

**Keywords**-Strandbeest, Jansen mechanism, Jansen linkage, walking machine

## 1. INTRODUCTION

To solve the locomotion problems many researchers and engineers are try to take inspiration from nature. The morphology of multiple legs and their flexibility and coordination are the main focus of study for creators interested in mimicking biological behavior. And the person who successfully imitates nature is Theo Jansen.

Theo Jansen is a Dutch artist who invented "Strandbeest" machines the legs of which are commonly known as the Jansen linkage or mechanism. He postulated a mechanism consisting of rods of different lengths that were linked in conjunction to each other so that it resembled the structure of an insect leg. He successfully uses a simple rotary input for locomotion, thus deserving both artistic and mechanical merit.

This mechanism has generated a lot of interest and enthusiasm among researchers, especially in finding useful applications based upon its core concept. Some researchers also proposed some modifications and improvements to increase its usability for different applications. From the literature collected we can say that most of the applications are still in the developing or prototype stage and no machine or product inspired by the Jansen mechanism has gone for mass production. With more advancement in the technology available for design and manufacturing, there is still a lot of scope for research

In transporter vehicles traditionally wheel mechanisms are used such as in cars and trains. Wheels are ideally suited for movement without vertical fluctuations of the body, and tires with inner rubber tubes absorb shock from a rugged road. On the other hand, biologically-inspired robotics learns mobile flexibility from the morphology of multiple legs and their coordination. Good examples of this are arthropods, like spiders, and the robots are conventionally designed with actuators placed in every joint. In such implementation, robots are good tools to investigate how an animal moves, but they are unable to be a substitute principle for wheels because they don't much take into account the maximum load capacity. Joint's actuators promise mobile flexibility, while the actuator's torque performance impacts on the toughness of the robot's body.

Theo Jansen has attempted to create a bridge between art and engineering by focusing on biological nature, proposed a linkage mechanism to mimic the skeleton of animal legs. This is called “Theo Jansen mechanism,” and provides the animal with a means of moving in a fluid manner. Interestingly, his artificial animals require no electric power for actuators, and do work by weak wind power to drive the unit of multiple legs through a transformation of internal cyclic motion to an elliptical orbit of the legs.

### 1.1. Jansen Mechanism

Jansen mechanism consists of 11 links connected in tandem to each other to simulate a walking mechanism which is quite similar to that seen in crabs. It is a result of evolutionary computed models which Theo Jansen started to work upon in 1990. Out of all the links, one particular link acts as the rotational input which results in the walking motion of the entire linkage. The links synchronize together to trace an elliptic trajectory which gets sharpened at the moment when the leg touches the ground. When two Jansen linkages are connected to each other by a rotating horizontal shaft, both the legs help the machine to move forward or backward depending on the clockwise or anticlockwise rotation of the shaft. This is closely comparable to a wheeled arrangement in cars where two wheels are connected on both sides of a rotating axle and the shaft rotates by 120 degrees per stride. Interestingly, the relationship of the hind limb with the fore limb is antiphase, thus helping them to move forward cooperatively. The parallel link in the Jansen linkage helps the linkage to attain the required step height by folding during the cycle angling of the leg.

Theo Jansen mechanism is a single degree of freedom mechanism. In robotics, chain links are mainly of two types: open chain and closed chain. In the open chain, the final link, where the chain terminates, has multiple degrees of freedom, whereas in a closed chain linkage, the link, at which the chain terminates, does not have multiple degrees of freedom and is restricted to repeat the same motion throughout its life. The Jansen linkage is a closed chain linkage. Though this would handicap the machine to some degree but it significantly reduces the number of actuators and is suitable enough for multiple applications.

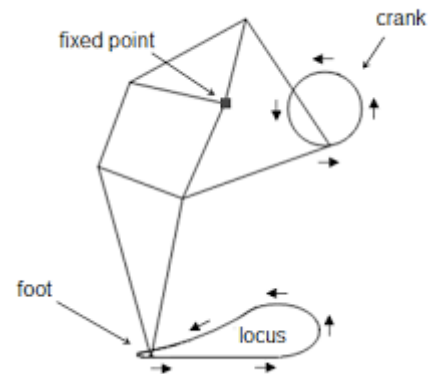


Fig 1- Eight bar linkage with locus

### 1.2. Advantages of walking

Walking machines possess several advantages over wheeled machines in areas of variable terrain. Consider a wheel moving a constant velocity  $V$ ; every point on its perimeter is moving at a constant velocity  $V$  tangent to the curve of the wheel as shown in Figure 2. A comparable walking mechanism would be one which moves at a constant velocity  $V$ , and where the “foot” traces out a similar circular path with a constant velocity  $V$  at all points on the path (also shown in Figure 2). The most obvious advantage of the foot over the wheel is that the foot may step over inconsistencies in the terrain. Local maxima and minima may be completely avoided by simply stepping over them. This results in less loss of energy during locomotion and allows the vehicle to maintain a constant velocity and height over variable terrain.

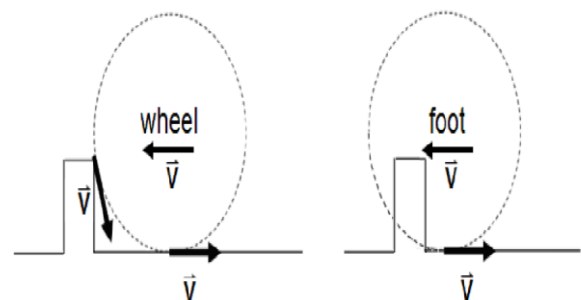


Fig 2- Comparison of wheel and foot response to a local maximum in the terrain.

The dotted lines indicate the perimeter of the wheel or the path of the foot. The arrows indicate the direction of movement. The foot may step over the obstacle completely, while the wheel must move over the obstacle.

Now consider a case where the comparable foot and wheeled systems approach an obstacle that cannot be avoided, as shown in Figure 3. When the edge of the wheel makes contact with the higher ground, it forces the velocity of the vehicle to immediately slow. This edge has a total velocity  $V$ , but only a fraction of that velocity is in the  $x$  direction, so the vehicle quickly slows from  $V$  to  $V_{x2}$ . The foot encounters a similar change in velocity, but it has the advantage of being able to slide along the ground. Although this scenario is not ideal, dragging the front foot across the raised terrain reduces change of velocity in the  $x$  direction. Both models must still overcome the potential energy barrier posed by the increased height of the terrain.

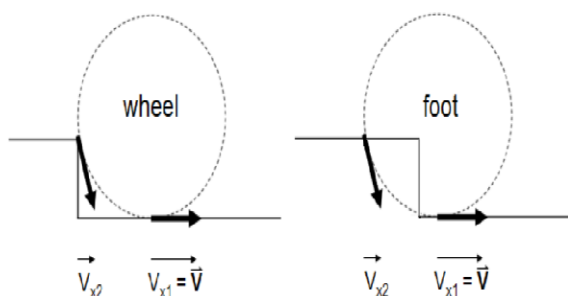


Fig 3- A comparison of a wheel and a foot (moving in a wheel-like path)

This shows approaching an inconsistency in the terrain. The  $x$  component of the velocity of the edge of the wheel and the foot's path are indicated. Furthermore, the wheel causes a great deal of environmental harm. Its inability to avoid obstacles means that it erodes more terrain than a foot when moving comparable vehicles. Additionally, wheeled vehicles work best on terrain with no inconsistencies; this has led to paving of many permanent roadways, another form of environmental degradation.

## 2. LITERATURE SURVEY

According to Webster and Warson, a good literature review acts as a foundation for knowledge enhancement and new theory formulation. For extensive literature review two majorly known databases have been referred to, that is, Google Scholar, Science Direct.

The various literature surveys are as below:

**Swadhin Patnaik** conducted research on four legged walking machines [1]. After researching about mining and excavation industries I came across with these data. The statistics suggests that about 50% of mining cost is spent on roadway and rail transports in the vicinity of the mines (haul roads & side rails). Haul roads cause a great damage to tires of transporting vehicle requiring frequent and regular replacement. Maintenance cost of haul roads is also high and it needs a separate wing. Weight distribution is uneven in haul roads causing higher stress problems in transport vehicles. On a rough terrain legs have advantage over tires so I came on Klann Mechanism. After researching through this mechanism on internet and going through few reports and watching its motion in the YouTube videos I found that Klann Mechanism has its own demerits which include steering and stability. After crossing out the Klann Mechanism from the list I stumbled on Theo Jansen Mechanism. This mechanism gave me the smoothest motion and is able to carry loads without much high forces applied to it. With the inspiration from Jansen's walking mechanisms, I began searching for various applications of the Jansen leg mechanism. I found several images and videos on the Internet showing different applications of this design large and small that helped me identify what I wanted my design to look like. The appropriation of the Jansen mechanism has ranged from tiny motorized robots to large multi-legged two-seater vehicles. This mechanism is very simple to build and it requires very less energy to run itself. But the only drawback found about this mechanism is its speed. How fast can it run? Except for that one point the Jansen design is incomparable with any other leg mechanism with such simplicity. AsalamEhshamsudin studied on the movement of robots in surfaces. In this paper the emphasis is given towards the mechanical structure of a quadruped robot able to walk on ground, climb on vertical walls, and perform the ground wall-movement automatically. The overview of the robot is shown, the configuration, number of DOFs, and the actuation system of the leg is analyzed. Biologically inspired gaits of the robot are discussed. The movement of the leg from the ground to the wall is analyzed. The integrated leg movement-trunk regulation sequences are simulated. And the trajectories of specific points on the trunk are traced, showing the limits for safe movement inside meandrous chimneys or zigzag tubing.

**Kazuma Komoda** and **Hiroaki Wagatsuma** studied on linkage mechanism of robots and proposed an extension

mechanism of the Theo Jansen linkage for climbing over bumps. The linkage is useful to mimic animal locomotion, we hypothesized that an additional up-and-down motion in the linkage centre provides different motion patterns from the original internal cycle. Our results demonstrated that the lifting up of the linkage centre alters the leg's orbit upward and the combination of a cycle and up-down motion provides a new elliptic orbit to climb bumps with about 10 times height of the original. This analysis may shed light on the future expandability of the linkage mechanism in bio-inspired robots.

**M.F. Silva** and **J. A. Tenreiro Machado** investigated on the optimization of legged robots. During the last two decades the research and development of legged locomotion robots has grown steadily. Legged systems present major advantages when compared with "traditional" vehicles, because they allow locomotion in inaccessible terrain to vehicles with wheels and tracks. However, the robustness of legged robots, and specially its energy consumption, among other aspects, still lag being mechanisms that use wheels and tracks. Therefore, in the present state of development, there are several aspects that need to be improved and optimized. Keeping these ideas in mind, this paper presents the review of the literature of different methods adopted for the optimization of the structure and locomotion gaits of walking robots. Among the distinct possible strategies often used for these tasks are referred approaches such as the mimic of biological animals, the use of evolutionary schemes to find the optimal parameters and structures, the adoption of sound mechanical design rules, and the optimization of power-based indexes.

**Yujiang Xiang, Jasbir S. Arora** studied on a review of human walking modelling and simulation is presented. This review focuses on physics-based human walking simulations in the robotics literature. it is mainly based on Physics-based modelling and simulation of human walking a review of optimization-based and other approaches. Features of various methods are discussed, and their advantages and disadvantages are delineated. The modelling, formulation, and computation aspects of each method are reviewed. José A. Tenreiro Machado Investigated on the optimization of legged robots the robustness of legged robots, and especially their energy consumption, among other aspects, still lag behind mechanisms that use wheels and tracks. Therefore, in the present state of development, there are several aspects

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## **2.1 Problem Statement**

It is well known that animals can travel over rough terrain at speeds much greater than those possible with wheeled or tracked vehicles. Even a human being, by "getting down on all fours" if necessary, can travel or climb over terrain which is impossible for a wheeled or tracked vehicle. Nature, apparently, has no use for the wheel. It is therefore of considerable interest to learn what machines for land locomotion can do if they are designed to imitate nature. With this idea in mind we started studying linkages and the comparative function of a set of linkages with certain degrees of freedom arrested. It turned out numerous implementations could be done so as to bring forth set of linkages so designed as to perform locomotion.

**1. Wheeled Vehicle** -In the present state of civilization the locomotion using wheeled vehicles is dominant. Its use for performing the most various tasks is so common that one might think this to be the only available (or more effective) way of locomotion. However, through a detailed analysis of the characteristics of this type of locomotion, it is possible to conclude that things are quite different.

**2. Wheeled Vehicle limitation**-It should be noted that wheeled vehicles demand paved surfaces (or at least regular) in order to move, being extremely fast and effective in these surfaces. At the same time these mechanisms can be simple and have a light weight. However, more than 50% of the Earth surface are inaccessible to traditional vehicles (with wheels and tracks) being difficult, or even impossible, that wheeled vehicles surpass large obstacles and surface unevenness. Even all-terrain vehicles can only surpass small obstacles and surface unevenness but at the cost of high energy consumption. An alternative consists on tracked vehicles. Although they present increased mobility in difficult terrains they are not able to surpass many of the

found difficulties and its energy consumption is relatively high. To these problems, one must add the fact that traditional vehicles leave continuous ruts on the ground, which in some situations is disadvantageous as, for instance, from the environmental point of view.

### **3. METHODOLOGY**

#### **DESIGN OF THEO JANSEN BASED FOUR LEG WALKING MECHANISMS-**

The total design work has been divided into two parts mainly;

- System design
- Mechanical design

System design mainly concerns with the various physical constraints and ergonomics, space requirement, arrangement of various components on the main frame of mechanism. The number of controls position i.e. fixed joints, motor position for ease of maintenance scope of further improvement, total height and weight etc.

In Mechanical design the components are categories in two parts.

- Design parts
- Parts to be purchased.

For design parts detail design is done and dimensions thus obtained are compared to next highest dimension which are readily available in market this simplifies the assembly as well as post production work.

The various tolerances on works pieces are specified in the manufacturing drawings. The process charts are prepared and passed on to the manufacturing stage. The parts are to be purchased directly are specified and selected from standard catalogues.

#### **SYSTEM DESIGN:-**

In system design we mainly concentrate on the following parameters.

##### **3.1. System selection based on physical constraints:-**

While selecting any m/c it must be checked whether it is going to be used in large scale or small scale in our case it is to be used in small scale so space is not a major constrain.

The system is to be very compact. The Mechanical design has direct norms with the system design hence the foremost job is to control the physical parameters.

##### **3.2. Arrangement of various components:-**

Keeping into view the space restriction the components should be laid such that their easy removal or servicing is possible moreover every component should be easily seen and none should be hidden every possible space is utilized in component arrangement.

##### **3.2.1. Component of system:-**

As already stated system should be compact enough so that it can be accommodated at a corner of a room. All the moving parts should be well placed and free to move A compact system gives a better look and structure.

- Design of machine structure
- Energy expenditure in hand operation
- Weighing condition of mechanism

##### **3.2.2. Chance of failure:-**

The losses incurred by owner in case of failure of a component are important criteria of design. Factors of safety while doing the mechanical design is kept high so that there are less chance of failure.

##### **3.2.3. Servicing facility:-**

The layout of components should be such that easy servicing is possible especially those components which required frequent servicing can be easily dismantled. i.e. battery, motor etc

##### **3.2.4. Height of mechanism from ground:-**

Fore ease and comfort of operator the height of mechanism should be properly decided so that he may not get tired during operation.

##### **3.2.5. Weight of machine:-**

The total weight of m/c depends upon the selection of material components as well as dimension of components. A higher weighted m/c is difficult for transportation and in case of major break down it becomes difficult to repair. We have tried to reduce the weight of overall system to meet its favorable conditions.

### **4. APPLICATIONS**

#### 4.1. Load-carrying tipper and trucks for mining integrated with Jansen Linkage-

A detailed study of this robot has been done by Patnaik. He explores and analyses the Jansen linkage as a permanent replacement for the wheels of load carrying tippers and trucks used in mining. The main aim of his research is to remove the problems associated with the smooth movement of vehicles at mining sites, which is commonly dealt with by making roads separately for it, a time consuming and costly process. Patnaik has chosen Jansen linkage over other mechanisms since it has the ability to bear huge loads while keeping its body steady.

#### 4.2. Crab-type robot

Kim et al. has proposed a crab-type robot based on Jansen's mechanism with the aim of solving many modern engineering problems. The most useful feature of this robot is that it can easily navigate on sandy or marshy surfaces where most wheeled vehicles fail. The developers have also worked on enabling the robot to be controlled over large distances by the operator with the help of a Bluetooth module integrated into its hardware. The robot is capable of carrying out all activities assigned to it while keeping its body stable. Many applications have been suggested by the developers which the robot will be capable of doing, such as providing intelligence, searching abilities, doing surveillance and also helping in special material scattering. Also, the option of integrating GPS in the machine has been suggested by the developers. With the help of GPS it can reach the designated coordinates marked by the user and also return to the user after completing the assignment.

Based on the specific application of surveillance, a coast guard type crab robot has also been proposed. The Bluetooth or RF controlled robot can operate on sandy and wet surfaces and is equipped with a vision camera which helps it to access its surroundings.

#### 4.3. Amphibian-legged robot

An amphibian type robot using Jansen mechanism has been discussed by Regulan et al. It is classified as an amphibian type robot because it has the ability to walk both on land and on water. Apart from the Jansen linkage for walking, the robot also utilizes Ackerman steering mechanism for turning.

The robot utilizes the principles of buoyancy to walk on watery surfaces. The design of the robot is inspired from the arachnid and it has six legs. The structural stability of the whole robot is investigated using finite element software i.e. ANSYS. It is proposed that this mechanism can be used both in surveillance and in exploration based activities.

A similar amphibious vehicle type robot has been created by Ting. The gears of the vehicle have been 3D printed while other parts are made with acrylic. The vehicle employs a single motor and has a walking speed of 2.17 cm per second and swimming speed of 1.1 cm per second. Its dimensions are 98 mm (width) by 86 mm (depth) by 65 mm (maximum height) and its weight is 131.6 grams.

#### 4.4. Sports ground/pitch-marking robot

In most countries pitch marking is done with the help of rollers and droppers. From marking to painting, pitch marking is both a time consuming and tedious process. To simplify this process researchers and engineers have started working on making robotic models of various kinds. Parekh et al. have proposed a robot without wheels based upon Jansen's mechanism for locomotion. The removal of wheels is an added benefit because the terrain of sports fields is not uniform everywhere. The robot model could carry much more weight than its own weight, provided the weight is evenly distributed. The robot is capable of marking the field with chalk powder, oil paint and water colour. The operator just has to feed in the distance to be marked by the robot and refill the paint tank when it is empty and the rest is handled by it. The authors propose with the help of some modifications the robot could also be used for ploughing, seed sowing and gardening in the future.

### 5. CONCLUSION

The literature collected provides us with an idea of the various application possibilities based on the Theo Jansen mechanism. Most of the literature collected provide us with a hint that most of the applications described are still in a proposal or prototype level and have not yet been mass produced. The literature collected is based on the internet database and no case study is involved which investigates the usage of the

mechanism in practical life. It is the belief of the authors that the applications of Jansen mechanism would grow with time.

The belief relies on the rapid advancement of technologies like metal cutting and 3D printing which will enable developers to easily prototype their conceptual models and also go for mass production if the prototype seems a promising one. With the rising manmade and natural disaster threats, it is highly probable that there will be an increase in disaster management and surveillance robots incorporating Jansen's mechanism. Also, there is high potential for development of other applications like bomb disposal, security surveillance, spy operations, exploration, pitch marking, stair climbing, moving furniture, etc based on this mechanism in future.

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