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Study of Applications of Jansen's Mechanism in Robot

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Abstract
The natural and the manmade terrains on planet Earth vary from place to place. The availability of affordable and safe modes of transportation on the different types of terrain is currently costly and limited. This problem is mainly 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 crabs. 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.

1. Introduction

Wheeled vehicles are not suitable for rough terrains due to various limitations [1-3]. The speed and stability of automobiles, compared to that of most animals, is far below requirement on uneven terrains [2]. It is also practically impossible for most automobiles to move over vertical surfaces, unlike spiders and many other insects which crawl over walls with ease and flexibility [2]. Even on very sandy and marshy surfaces most automobiles slip frequently [1] when in motion, whereas crabs and lobsters crawl around effortlessly.

The facts mentioned above indicate that there is still a lot of scope left for changing the way in which humans or vehicles commute in the 21st century. The invention of new ways of locomotion or modifying an existing mechanism can enable myriad applications of the technology. One of the most useful applications for such new mechanisms could be easy movement of a vehicle over rubble, houses and roads destroyed by earthquake, tsunami or any other man-made or natural disaster [3]. Another useful application can be the locomotive mechanism of vehicles or machines used for mining [2]. Usually, mining sites are extremely bumpy and rough, so roads have to be made separately for vehicles, thus enabling smooth mining operations [2]. However, this causes the mining agency to bear more cost and also increases emission levels. The problem can easily be tackled with mechanisms that can help the vehicle to move easily over any type of surface. Other useful applications related to the above are bomb disposal, security surveillance, spy operations, exploration, pitch marking etc.

Most researchers, artists and engineers try to take inspiration from nature to solve the problems of locomotion. The morphology of multiple legs and their flexibility and coordination are the main focus of study for creators interested in mimicking biological behaviour. One of the most reputed persons to successfully imitate nature is Theo Jansen. Theo Jansen is a Dutch artist who invented "Strandbeest" machines [4, 5], 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. It has garnered a lot of appreciation for its beautiful simulation of organic walking. It 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 [3, 6, 7, 8] 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.

The literature collected indicates that most of the research and development is taking place in East Asian countries. The review also shows that developing countries like India are also taking interest in this mechanism. Considering that the Jansen linkage originated in a European nation, the amount of literature available on the subject in European countries is significantly small.

This paper discusses the applications of the Theo Jansen mechanism proposed till date. The paper has been organised as follows: Firstly the Jansen Mechanism has been explained. The explanation is followed by a description of the literature collected. This is followed by the proposed applications till now. The literature review ends with a conclusion and discussion regarding the future scope of its applications.

2.Jansen Mechanism

Jansen mechanism [5] 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 ecliptic 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.

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 [6, 9] and is suitable enough for multiple applications.

3.Material Collection

According to Webster and Warson [10], a good literature review acts as a foundation for knowledge enhancement and new theory formulation. To do justice to this review, material collection has been given significant importance.

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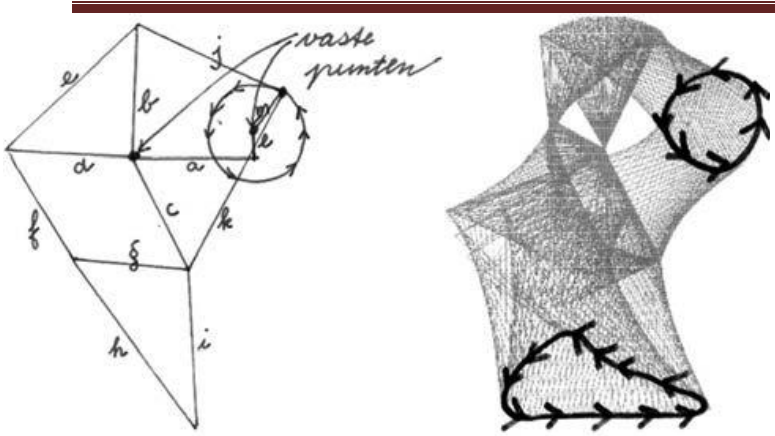

Fig. 2: Leg Mechanism Diagram[www.strandbeest.com]

For extensive literature review four majorly known databases have been referred to, that is, Google Scholar, Science Direct, Taylor and Francis and Emerald Insight. The common key words used in all four are "Jansen's mechanism", "Jansen's linkage" and "Theo Jansen". The results in Science Direct, Taylor and Francis and Emerald Insight were insubstantial and not relevant in view of the discussed review. But the results from Google Scholar were promising. The keywords "Jansen's Mechanism" generated 116 results and these results were sorted according to the requirement of the literature review. The results from the other two keywords were not as relevant or similar to that generated by the keywords "Jansen's Mechanism", thus these results were ignored.

Out of the 116 results for Jansen's mechanism many spoke about further improving the mechanism. All these papers were also classified as irrelevant as this paper mainly focuses on the applications of Jansen's mechanism. Google Scholar mostly redirected to digital library IEEE Xplore and East Asian databases for the majority of the papers available. After investigating all the results, 12 papers were selected based on their relevance, content and ease of translation. For describing the problem and introducing the topic some papers on improving and analysis of Jansen's mechanism were also referred. Since all latest applications are not available on digital library, Google news search was also used with similar keywords and from there two more web pages (hackerday.com; hackerday.io) were referred to for the literature review.

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 [2]. 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 [11]. 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 [11]. 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.

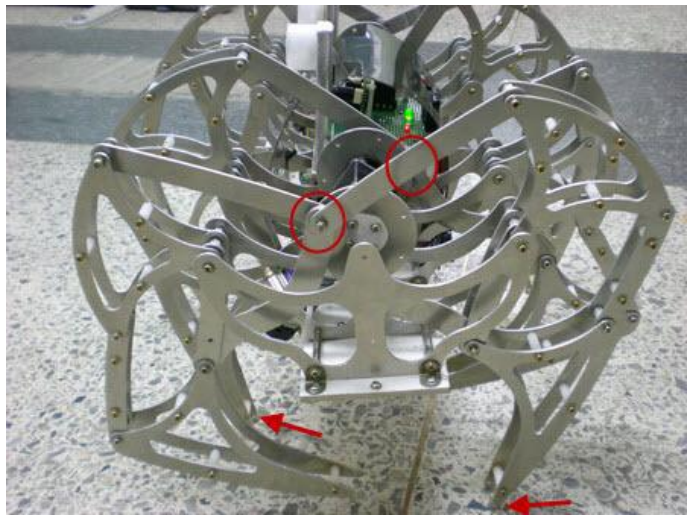

Fig. 3: Crab Type Robot[11]

4.3 Amphibian-legged robot

An amphibian type robot using Jansen mechanism has been discussed by Regulan et al.[12]. 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 utilises Ackerman steering mechanism for turning. The robot utilises 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 [13]. 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 [14]. 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 [14]. 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.

4.5 Robot for stage performance

A robot inspired by Theo Jansen's Mechanism called Mei Mei was developed by Dong [15] for an opera stage performance called 'Death and Powers'. The robot developed had six legs driven by two separate motors and could move forward, backward, and turn around with varied steering control. The robot could be operated

with the help of a remote and motor controller. The basic aim of this robot was that it should look like moving furniture in the play.

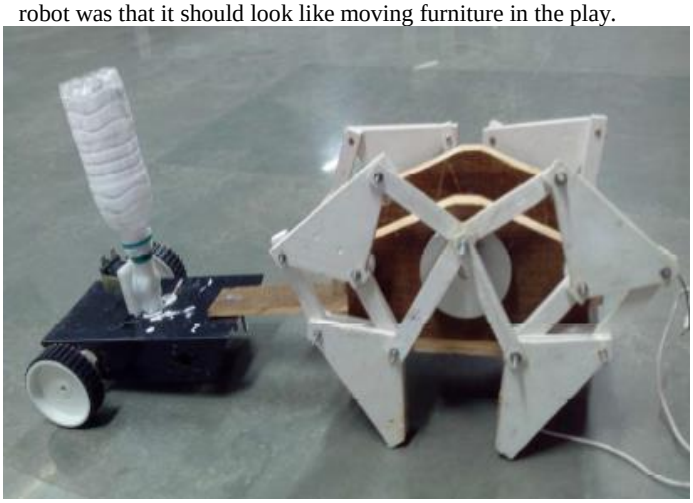

Fig. 4 : Pitch-Marking Robot [14]

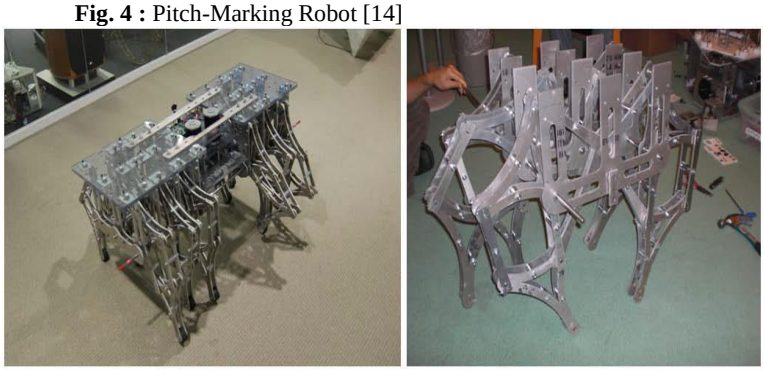

Fig. 5 : Mei Mei robot and its legs[15]

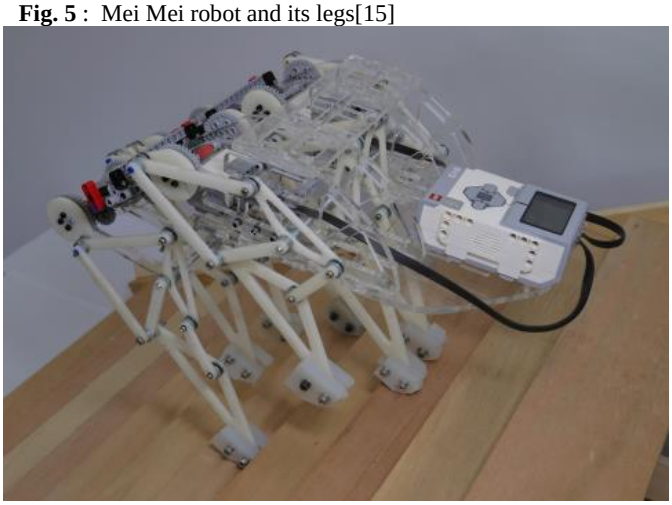

Fig.6 : Stair-climbing robot [16]

4.6 Stair-climbing robot

Liu et al. [16] have built a prototype which mimics the human ankle and easily climbs stairs of different step heights. The robot is eight legged and is based on the Jansen's mechanism. The robot does not crawl or bump over stairs but smoothly climbs stairs with human foot-like trajectory, while keeping itself steady. The prototype is built with plastic materials but the authors plan to use metallic materials in future as it would reduce the deformations caused earlier due to use of plastic material. The authors believe that this invention would enable various applications especially for high speed stair climbing.

A similar robot with the objective of enabling applications like rescue, information collection/detection and assistance has also been developed by Chord [17].

4.7 Strandbeests

The Theo Jansen mechanism, the applications of which have been extensively talked about in this paper, is a part of huge wind-powered machines called Strandbeests. These machines are the products of 15 years of work done by Theo Jansen. The Jansen mechanism or the Jansen linkage only helps these machines to walk; a lot of other mechanisms are also present in these machines. Even after being the prime invention of Theo Jansen involving Jansen mechanism, the reason why it has been talked about at the end of this literature review is that it does not have as much practical life application as designated to it by its creator. It is solely created for the purpose of removing the barriers between art and engineering. But the machines are a wonder in themselves. They are made out of PVC pipes, can detect water and turn around, can pin themselves to the ground on detecting strong winds and are completely wind powered. They are called 'Strandbeests' (plural) because many types of Strandbeests have been created with the help of genetic algorithms by Theo Jansen. Though the mechanism in itself does not have any applications apart from decoration of beaches, it has inspired many other researchers, engineers and artists to make machines that are similar to it and have specified applications [5].

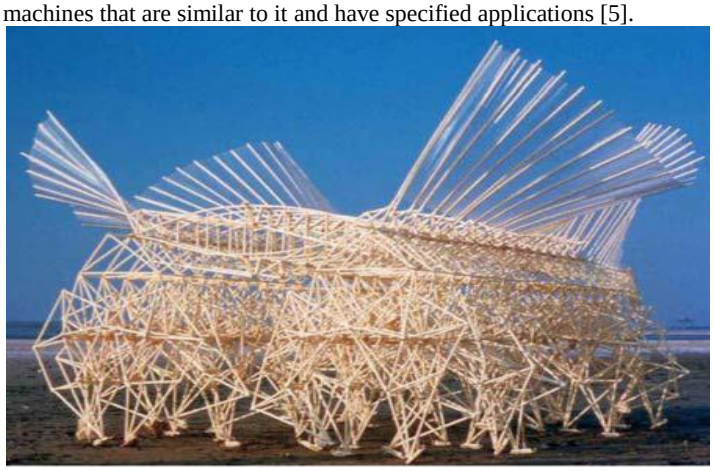

Fig. 7: Strandbeest [21]

4.8 Lion-type robot

A medium-sized quadruped robot, similar to the Theo Jansen mechanism, has been developed [9]. In order to make its gait biomimetic, it has been developed by using only one electric motor as an actuator for walking and running. The usage of a single actuator drastically reduces the size in comparison to robots with multiple actuators which are very big in size [9]. For the purpose of successfully developing this mechanism, a modified gallop gait has been used which is primarily derived from the bounce and gallop gait. The robot can also perform dynamic running, achieved by making the fore and the hind legs touch the ground alternatively.

The robot employs a battery operated system with a capacity of 1800 mAh and has a velocity of 0.89 m/s.

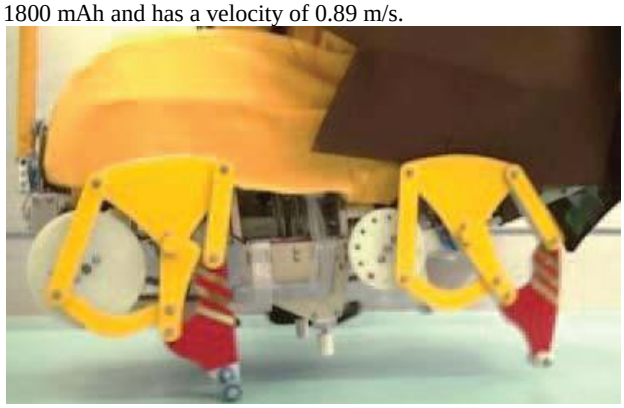

Fig.8: Lion-type robot [9]

Some other applications include the Jansen mechanism-inspired bicycle [18], moving furniture [19], moving jewellery [20] etc.

5. Conclusions

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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