Robot based on walking Jansen mechanism

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Abstract. Walking mechanisms can move across different terrains. They are usually based on planar linkages with single degree of freedom. Basic idea is to, through observing human and animal locomotion, create a linkage that is more efficient while crossing rough terrains. Theo Jansen, one of the most popular walking mechanisms, is 8-bar mechanism with single degree of freedom. In this paper are presented analysis of the walking mechanisms, advantages of walking mechanisms in comparison with classical wheeled machines and the effect of certain parameters on its performances. The locus analysis was performed as well as the analysis of the leg when it touches the ground, which can contain solid information that can be of use.

1. Introduction
It is well known that animals can travel over rough terrain with much greater stability and at speeds much greater than those possible classical wheeled vehicles. For that reason it is interesting to consider locomotion and try to integrate it in engineering.

When talking about locomotion, first thing that comes to mind are walking, legged mechanisms. Walking platforms are probably best design strategy for locomotion of a robot. They are usually 1 degree of freedom planar linkages, and they are able to move across rough terrains.

2. Walking mechanisms
Walking mechanisms are suitable for applications that require movement across rough terrains, especially if compared to conventional wheels. They consist of links and joint, and are intended to simulate walking of human or animal. These linkages can be planar with single degree of freedom, or they can have a more complex motion in 3 dimensional space. Some can have multiple degrees of freedom.

2.1. Flaws of walking mechanisms
The shortcomings of the walking mechanisms are as follows:
- A driving member rotates in a unequal speed to obtain a unique speed of robots, or vehicles that are driven by a walking mechanism.
- The length and height of the steps are fixed.
- Inertial moments and forces cannot be balanced in a satisfied way.

2.2. Advantages of walking mechanisms
When it comes to the advantages of walking mechanisms, first of all, it is necessary to mention the movement on rough terrain. It can move on all types of terrains like desert, mountains, snow, rocky. It can be even used in planetary exploration because it has maximum payload to weight ratio. Also it has maximum efficiency for moving.

These benefits of using walking mechanisms include higher speed, better fuel economy, greater mobility, better isolation from terrain irregularities, and less environmental damage.

2.3. Advantages of walking mechanisms when passing an obstacle

If we compare this mechanism with a common wheel, it is obvious that the walking mechanism will overcome an obstacle much easier by just crossing it.

Consider a moving wheel with a constant angular velocity ω, each point on the circumference of the circle will have a velocity ν, in the direction tangent to the circle. The picture shows that the wheel cannot overtake the obstacle. Now we observe a walking mechanism moving at a constant velocity v, its leg would describe a similar circular path. It is clear that the leg will have an advantage over the wheel, because it will be easier for it to overcome the obstacle. This way you can reduce the consumed energy.

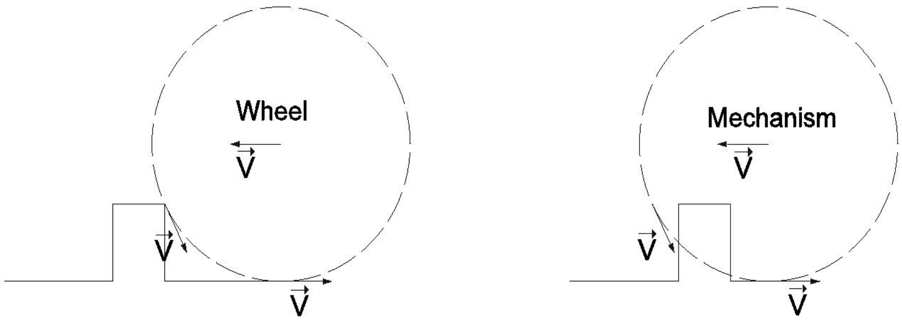

Figure 1. Wheel and foot crossing over an obstacle. The arrows indicate the direction of movement of the wheel and the leg [1].

Often in practice, you can find an obstacle that cannot be overrun, such as stairs. When the wheel comes into contact with the edge of the obstacle, the speed will be sharply reduced. The picture shows that the horizontal component of the speed is small. With the walking mechanism, the horizontal speed is also, but its advantage is that the foot can slide on the surface. It can still be seen from the figure that vertical displacement is required, which is an additional energy consumption.

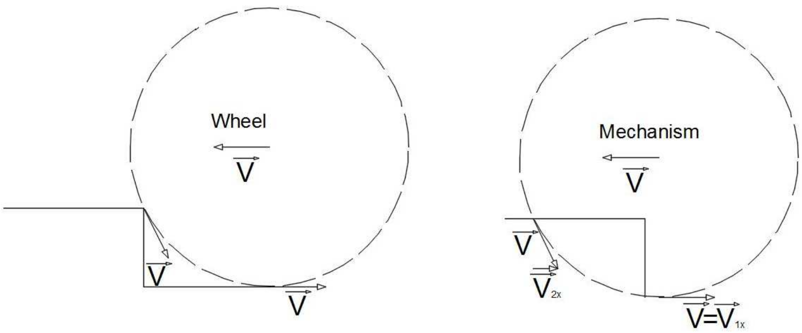

Figure 2. Wheel and leg crossing over an obstacle that cannot be overrun [1].

3. Locus

When walking, a leg generates a curved line. This line is called the locus, and it contains all the points through which the leg passes per rotation of the driving member. The way to get this is to look at the terrain, which moves in the opposite direction relative to the movement of the robot at the same speed. Locus has 4 stages:

- Stride - this is the step of the locus when the foot is in contact with the terrain. At this stage, the speed is constant.
- Lift - during this phase, the leg is lifted to the maximum height.
- Return - the leg moves in the opposite direction in relation to the stride, and is at the maximum height.
- Lower stages - the leg is lowered until it comes into contact with the terrain. The curve, which is generated during the lifting and the lowering stage, holds the information on how the foot contacts the terrain.

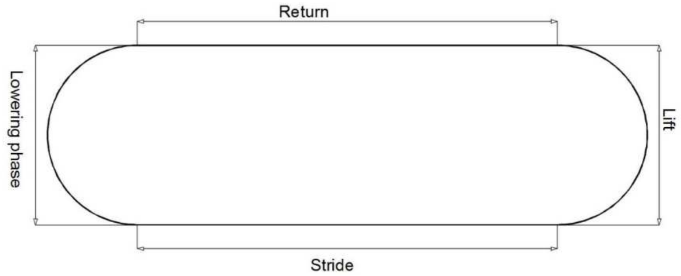

Figure 3. Locus [1].

3.1. Shapes of locus
Depending of mechanism type locus has difrent shapes. The next figure shows five theoretical forms of the locus.

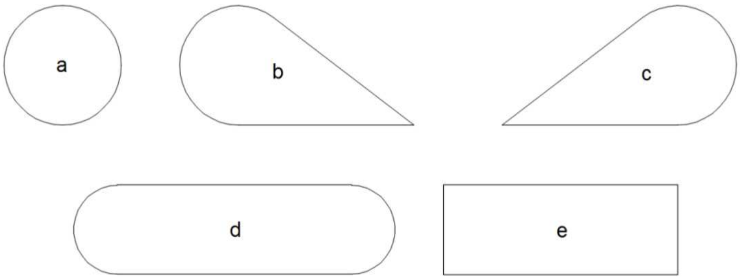

Figure 4. Theoretical shapes of the locus [1].

Locus a has the lifting and lowering stages as well as the wheel. This mechanism is not effective because it has a low-drag phase.

Locus b and c can cause unsatisfied performance due to high acceleration at pointed ends, as well as the way they come into contact with the terrain.

Locus e is rectangular and offers many advantages. However, the problem occurs when it comes into contact with the terrain during the lower stage, then the mechanism may be blocked or slipping may occur. Similarly, for the mechanism to reach constant speed in the stride phase, it will require infinite acceleration at the beginning and end of the same phase.

Locus d is theoretically ideal, and represents a compromise between circular and rectangular. It has a long stride phase. The lifting and lowering stages are the same as for the wheel and have the same acceleration characteristics as the circural locus. It is possible to balance the inertial forces by properly phasing a number of mechanisms on the terrain.

4. Motion of the foot
When classical vehicle is moving its wheel contacts all particles of road. On the other side, leg of a walking robot contacts only spots of small areas along the path. It is possible that next contacted area

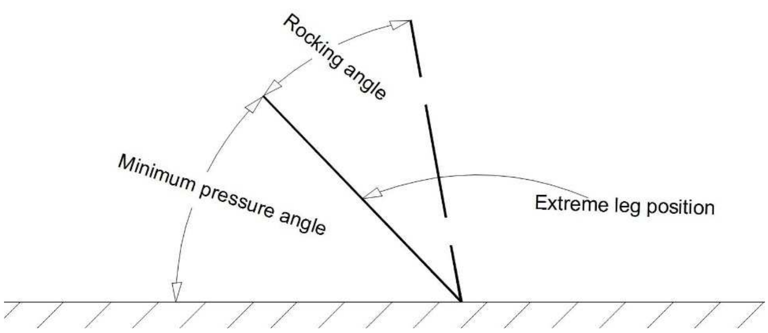

Figure 5. Leg in contact with the ground [1].

will be on higher or lower altitude then the preceding one. It is good idea to analyze this situation.

When in contact with the ground, during stride phase, leg has a rocking motion relative to the ground. Depending of diffrent mechanisms this rocking angle varies, in some mechanisms this angle is on the direction of movement of the robot, while in some it is in opposite direction. Rocking angle affect leg forces.

Rocking angle can be defined as diffrence between maximum and minimum pressure angle. Maximum pressure angle is angle of leg relative to ground and minumum pressure angle is angle of extreme leg position relative to the ground.

4.1. Velocity of the foot

The foot speed in relation to the robot and the backbone could be written as follows

$$V_{ft} = V_{fr} + V_{rt} \tag{1}$$

Where:

V_{ft} - foot speed relative to the terrain.
V_{fr} - speed of the foot relative to the robot.
V_{rt} - speed of the robot relative to terrain.

From this formula it can be seen that the velocity of the leg relative to the terrain is equal to the sum of the robot velocities relative to terrain and the leg relative to the robot. In the stride phase of the mechanism, when there is no slipping, the leg velocity with respect to the base is equal to zero, It follows that:

$$V_{fr} = -V_{rt} \tag{2}$$

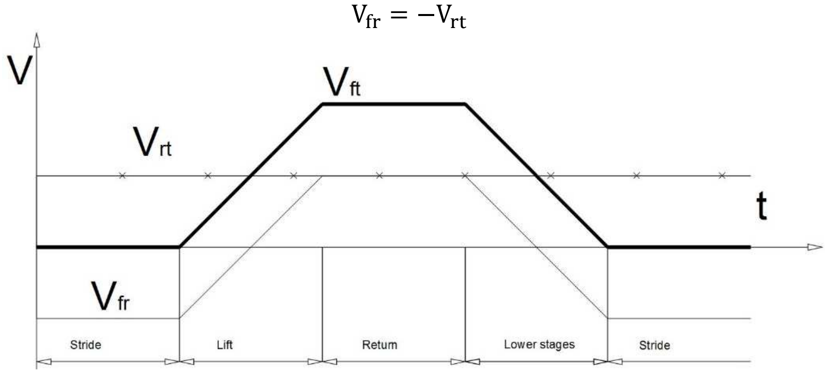

Figure 6. Velocity diagram [1].

It is seen that the velocity of the robot relative to the terrain is constant during each phase. During the stride phase foot speed relative to the terrain is zero and during the return phase, we see that the foot speed relative to the terrain is twice as high as the speed of the robot relative to the surface. We also see that in the half of the lift phase and the lower phase, the speed of foot relative to robot is equal to zero and that at the beginning of the lift phase the speed of leg is lower than the speed of the robot. This means that if the foot was still in contact with the terrain at this moment and an obstacle was encountered, the robot would drag the foot over the surface, or obstacle. The same happens at the end of the lower phase.

5. Jansen mechanism

Jansen linkage is walking mechanism designed by Theo Jansen. It belong to group of 8-bar planar mechanisms with single degree of freedom. This mechanism consists of 5 line elements and 2 triangle elements. One of triangles is „foot“ of this mechanism.

One of best features of such mechanism is that part of the rotating mechanism can be attached to the crankshaft, which makes it easy to rotate. As the crankshaft rotates, this linkage creates a sort of eliptic shape that sharpens just before touching the groud. That is locus of this mechanism. In following Figure shematic view of Jansen mechanism, his locus as well, is shown.

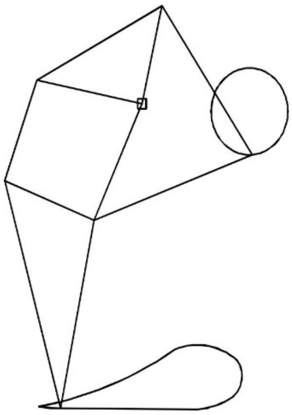

Figure 7. Jansen mechanism and its locus [1].

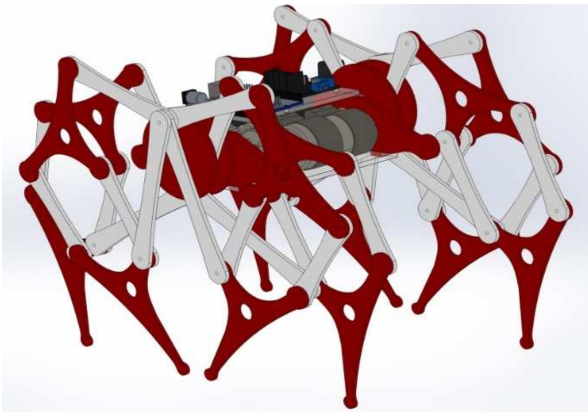

Figure 8. 3d model of robot.

6. Walking robot

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.

In this case one side of robot has 4 Jansen linkages, which present 2 legs and in total 4 legs, in order to balance out inertial forces, and increases stability of robot. By increasing number of legs these forces are dampened, due to the shape of locus.

6.1. Control of robot

Cranshaft is driven by 12 V DC motor, which is located on top of the robot. Easiest way to control this motor is to use Arduino microcontroller environment and H-bridge. By using PWM pins from Arduino. Both sides are connected to the same shaft, so this robot can move only back and forward. Arduino is controled from PC via infrared module.

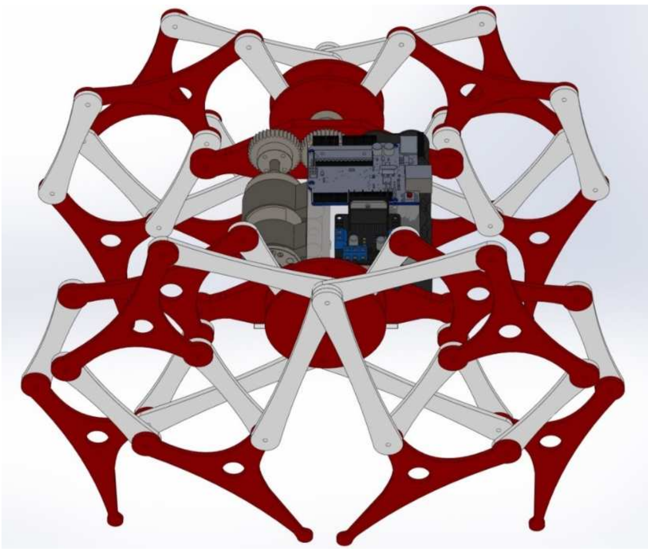

Figure 9. Top side of the robot.

6.2. Prototype of robot.

In next Figures prototype of this robot is shown.

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Figure 10. Prototype of robot.

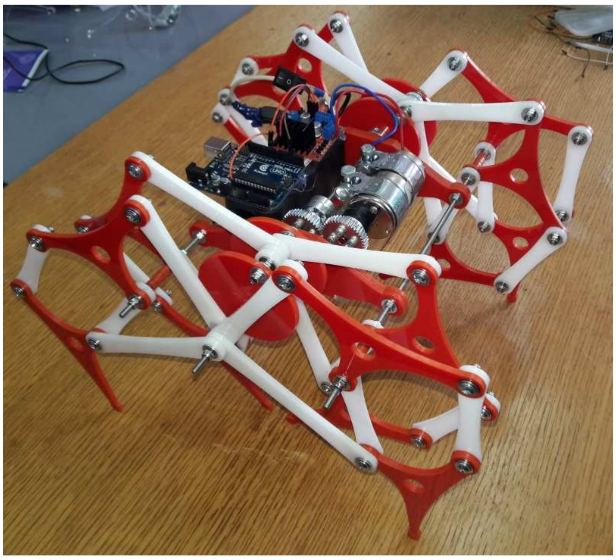

Figure 11. Prototype of robot.

7. Conclusion

The main problem of a single degree of freedom walking mechanisms controlled by rotary actuator is that its locomotion capability is limited, because the leg gets stuck following a fixed curved line. However, on the other hand its advantages such as when encountering an obstacle and energy efficiency, which are shown above, are more than sufficient reason for its later scientific consideration. After all, this developed model of Jansen mechanism can find its application in further development of walking robot.

The goal for the future is to create the same platform and to connect it with the existing one, to work simultaneously, so that steering can be achieved by controlling motor speeds. Next step would be to equip it with sensors to achieve autonomous motion.

References

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