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Four-legged Spider Robot to Walk Over and Clean Vertical Glass Surfaces

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ABSTRACT

In the current era of robotic world, various types of spider robots for various purposes are being developed. The objective of this project is to develop a reliable robot to walk over vertical glass surface. This type of robots can be used very efficiently to clean glasses of big buildings which were build using glass surfaces. In this paper, an algorithm is proposed to make four-legged robot to walk in various directions and also to scan full surface based on the coordinates passed to the robot, in order to clean the full glass surface. This also consist of IoT device to send the single to operator to monitor the movements and radar to detect any object. Since this robot is to walk over the vertical glass surface, integration of vacuum suction holds to the algorithm is a new and challenging part of this project.

Keywords : IoT, Vacuum Suction Hold

I. INTRODUCTION

Now a days, every building either office workspaces or residential apartments are being build using glass as outer surface. To maintain these types of buildings, people are spending lot of money for cleaning these outer surfaces. Spending money is one side of the effort and the main risk factor in this process is, people are cleaning these glasses by hanging through ropes as shown in fig1. There are many incidents where many people are died while doing this process.

Fig-1 People cleaning glass surfaces

So, to avoid these types of incidents and maintain the glass clean, a robot has to be designed to ease this work. With this motivation as primary target, a four-legged spider robot with four legs connected with vacuum suction cups to hold the glass and walk over the glass. The robot should either be driven from the base station or remote location that should send all available data from sensors, which will be displayed on the computer in the user interface program. It is also important to create and program a system into the IoT controller, which would have the capacity to control the servomotors and sensors and pass the information to remote system online.

II. BACKGROUND

Examination of walking machines started in the nineteenth century. One of the first models showed up around the year 1870. For 80-90 years, endeavors were made to build walking machines based on different kinematic chains that were supposed to generate a desired motion profile during operation. During those years, numerous models were proposed, yet the execution of a large portion of these machines was constrained by general cyclic s walking forms and the inability to adjust a walking pattern to the landscape. In the late 1950s, it turned out to be clear that machines ought to not simply be based on kinematic mechanisms that provide cyclic movements, and that there was a need to integrate planning and control systems. The first robot to move independently with computerized control and electric propulsion was built in 1966 by McGhee and Frank. The main task of the robot's computer was to unravel the kinematic equations involved and to control the electric motors that drove the legs, such that the robot could go forward while maintaining equilibrium constraints. Since then, and following the advance of control technique technologies, computing resources and motion actuators, many different robots with varied abilities have been built.

In 2003, AMIR SHAPIRO in this paper he has developed a spider like robot with two main features as development target 1) stable movement and 2) destination finder to achieve stable locomotion. The control method is based on new results in the fields of grasp theory, and control of asymmetric 2nd-order linear systems. The control method ensures that when a spider-like mechanism bracing against the environment at equilibrium posture the naturally occurring compliance at the contacts stabilizes the mechanism as a single rigid body. Next an algorithm, named PCG (Preconditioned Conjugate Gradients), for selecting sequence of foothold positions along the tunnel has been developed. This robot is developed to use in a situation like, surveillance of collapsed structures for survivors, inspection and testing of complex pipe systems, and maintenance of hazardous structures such as nuclear reactors, all require motion in congested, unstructured, and complex environments.

In 2013, Yam Geva [11] developed, a spider like robot is designed to traverse rough terrain while carrying additional payloads. Such payloads can include both sensors and computational hardware. To develop the forward kinematics equations, we use rotation and translation matrices combined in homogeneous transformation matrices. We chose to use the zero reference point (ZRP) [12] representation method although the Denavit-Hartenberg (DH) [13] method can also be applied.

In 2014, Sachin Oak [14] and Vaibhav Narwane presented a paper on design, analysis and fabrication of a quadruped robot of weight 1.71 Kg incorporates four bar chain leg mechanism as its locomotion element. Mechanical design gait analysis and fabrication of the robot is discussed. Quadruped robot designed and fabricated here involves 8 degrees of freedom which are controlled by servomotors and it walks on flat terrain using symmetrical gaits viz. trot and pace. Its locomotion is controlled by controlling angular rotation of servomotors.

Prof. Atish.B.Mane & Atharva Barje has done research conducted on replacing the wheeled robot with legged robots by using two major mechanisms Joe Klann's Mechanism and Theo Jansen's Mechanism. They majorly taken the Joe Klann's Mechanism for the development of robot. The Joe Klann's Mechanism is a planner mechanism simulates the walking mechanism of the spider. Mechanism consists of crank, rocker arm, leg, frame all connected with pivot joints.

In 2018, Rozita Teymourzadeh [16] had presented the development of an adaptive intelligent spider robot, with various sensors as feedbacks to the control system to take a decision for the next footstep. In this project, the whole control system was developed using national instruments [NI] controller. The simulations are extracted and monitored using LABVIEW interface. The various sensors used in this project are GH-311 Ultrasonic Sensor to detect any obstacle in front of the robot, GH-312 Smoke Sensor which use to detect smoke in the particular area and LM35 Temperature sensor to get temperature for the surround. The proposed module was designed and implemented using movable wireless Router Module TP Link TL-MR3420 Router transceiver for device communication. The robot was tested and analyzed showing the system efficiency of above 95%, which is competent in robotic applications.

In 2016, Mr.V.Arun & Mr.S.V.S.Prasad [17] had presented an integrated perception and control system for a quadruped robot that allows it to perceive and traverse previously unseen, rugged terrain that includes large, irregular obstacles and also explain the overall structure of the Robot a monolithic mechanical structure and closed- system software architecture.

In 2018, Ritesh G. Waghe [18] had developed a reliable platform that enables the implementation of stable and fast static/dynamic walking on even or uneven terrain. The movement of robot is developed based on the most common way of creating gaits is by manual programming. More sophisticated methods exist and some of them include mimicking stick insects, evolving patterns using genetic algorithms or using artificial neural networks. Some of the most common gaits used are creep and trot gait.

In 2019, S.N. Teli, Rohan Agarwal [19] had presented a paper on how to fabricate mechanical part. In this paper, no prototype is developed, but the main aim is to design and fabricate mechanical multi-legged robot and deformation in the kinematics links by using CADD software. The analysis of the robot is based on the FEM concept integrated into Cad software called ANSYS R16.2. The aim of this project is to create an eight-legged robot to test new walking algorithm

III. CHARACTERISTICS OF LEGGED ROBOT

This part is focuses on several characteristics of walking robots. Some classifications of walking robots and most common walking gaits are described.

A. Classification of Walking Robot

There are many ways to define walking robots

- ✓ By a body shape
- ✓ Number of legs
- ✓ Number of degrees of freedom per leg
- ✓ Locomotion technique.

To achieve many different configurations various options can be combined. By body shape it can be classified into two category Mammal and Spider which is shown in Fig.1.

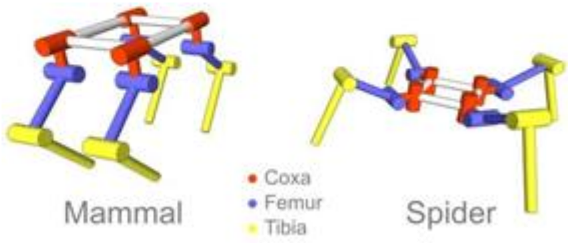

Fig -1: Mammal and Spider robot body shape

At least two degrees of freedom are needed to construct a walking robot – first for lifting the leg, second for rotating it. Nevertheless, for a good functioning robot there should be three degrees of freedom, because the legs move along a circle and the forward movement of the body causes slipping between the foot and the surface, which can be compensated by third joint..

B. Walking Theory

In order for the four-legged robot to walk, several algorithms need to work together to form a complete controller. The end product at every time interval is the position set-point for each servo. Walking patterns need to be chosen, swing trajectories calculated and leg position constraints updated. Depending on velocity, different gaits are selected by a controller. To execute these gaits each leg will have a stand phase and a swing phase. Whereas the stand phase is when the leg has ground contact at all time. During the swing phase a trajectory between two stand positions must be properly calculated by the controller. Due to size of hardware such as leg length, servo positions and body width, certain constraints will restrict the possible leg positions. The positions of each leg will also affect remaining legs possible position space. Due to resemblance between a quadrapod robot and legged insects a lot of inspiration can be taken from insect locomotion and biometrics.

1) Walking Gaits

To move a quadrapod in any direction the legs has to push it in that way, resulting in legs getting further away from the quadrapod body. In order for this to continue the legs have to be lifted and moved back into the vicinity of the body. This can be done in several different ways and possibilities increases with the amount of degrees of freedom. The most common way of creating gaits is by manual programming. More sophisticated methods exist and some of them include mimicking stick insects, evolving patterns using genetic algorithms or using artificial neural networks. Some of the most common gaits used are creep and trot gait. They are used for slow and medium movement respectively. The basic difference between these gaits are the usage of one or two legs simultaneously in swing phase, Figure 2.

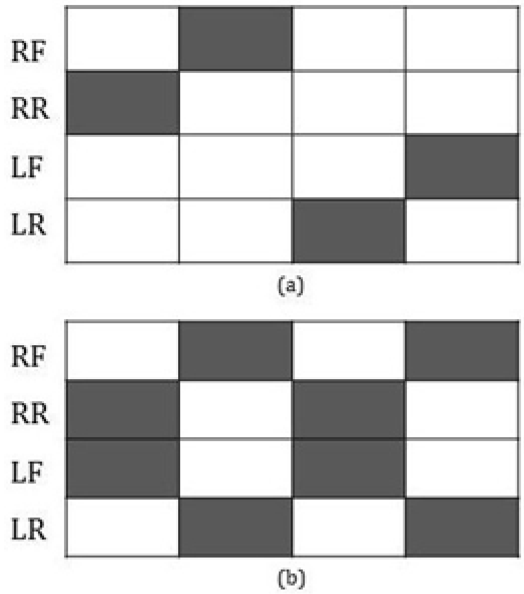

Fig -2: Gait diagram for two common gaits that can be implemented. Black symbolizes swing phase. (a) Creep, (b) Trot.

2) Creep Gait

The basic alternating diagonal walk called the creep, sometimes known as the crawl, it also known as static stable gait. The alternating diagonal walk has dynamic stability (Trot gait), the creep has static stability. Only one leg is ever lifted from the ground at a time, while other three maintain a stable tripod stance. The ground legs are maintained in a geometry that keeps the center of mass of a body inside the triangle formed by the three points of tripod at all times. As the suspended leg moves forward, the tripod leg shit the body forward in synchrony, so that a new stable tripod can be formed when the suspended leg comes down.

The tripod can shift the body forward simultaneously with the suspended leg, giving a nice smooth forward movement. This method should provide good speed on level ground. The tripod can shift the body forward after the suspended leg has touch down, giving a more tentative and secure forward movement this method should be useful when engaging obstacles or moving over broken ground.

The diagram below shows the basic timing for the leg positions when doing a creep gait.

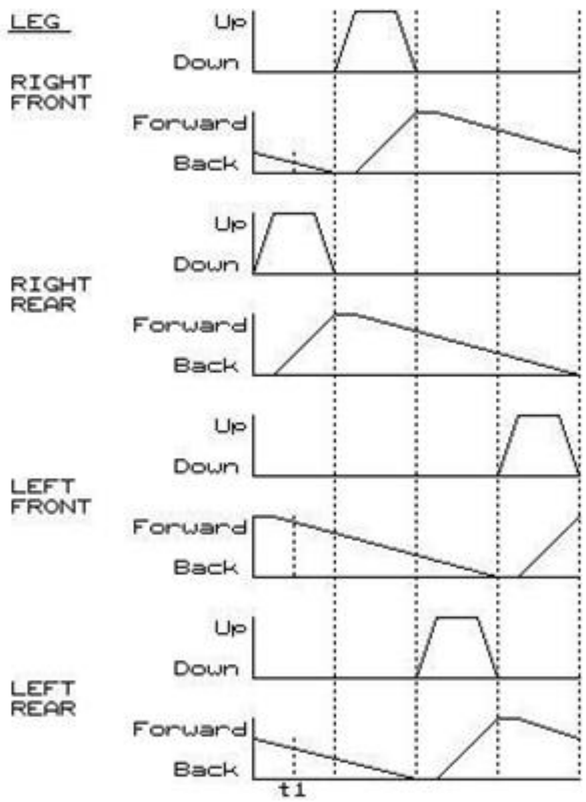

Fig -3 : Timing diagram for leg positions when doing creep gait

The creep gait works with 4-beat timing. One leg at a time, starting with the right rear, picks up and moves forward and down during one beat and then slowly moves backward during the next 3 beats. During the second beat, the front leg on the same side goes through the same motion. During the third beat, the rear leg on the opposite side does the same. Finally, the front leg on the opposite side does similar, during the fourth time beat. The cycle repeats, and forward motion continues. Each leg picks up and moves forward during its own quarter phase, and then moves backward during the other three-quarter phases. The overall action results in very smooth and even forward movement, since all legs are constant motion here. The body remains nice and level.

3) Trot Gait

The alternating diagonal walk has dynamic stability, its sometimes called amble gait. Two diagonal legs swing forward while the others two support the body and moves backward. It's one of the quickest gait because two of its legs are lifted at one time, although it's not very energy efficient.

The stability of the body is related to the frequency of the legs being lifted and placed, the quicker, the less shaky you will find it is. Of course, it's has something to do with the design of the feet as well, if the feet have a large contact are with the ground you will find it stay better while the other two legs are lifted. Since in this project, the robot should be able to walk on vertical glass surface, stability is far important that fast. So, for this project, Trot gait method won't be useful.

d. Inverse Kinematics

Each leg constitutes of three links (Coxa, Femur, Tibia) and three actuators (Body-Coxa, Coxa-Femur, Femur-Tibia). The first actuator connects the leg to the body. It is a shoulder pivot and is referred as γ. This angle controls the rotation of the whole leg in the plane parallel to the [x, y] place of the robot's body. The first link is called Coxa, is usually rather short and connects shoulder pivot with the elbow. Another actuator is placed between Coxa and Femur. The angle is called α and allows vertical movement of the leg. The Femur is connected to the Tibia with another actuator. It allows the set the angle between them. The angle is called β and operates in vertical plane as well. This angle allows to place the foot near or far to the center of gravity (CoG). Both angles α, β operate in the same plane, which is perpendicular to the robot's base plane. All the links in the leg has a fixed length. The actuators connecting the links are standard servos. The output horn of a servo can be set for angle 0–180°. Therefore a coordinate conversion between [x, y ,z] and angles α,β,γ must be provided

The conversion can be based on standard trigonometric functions and law of cosines.

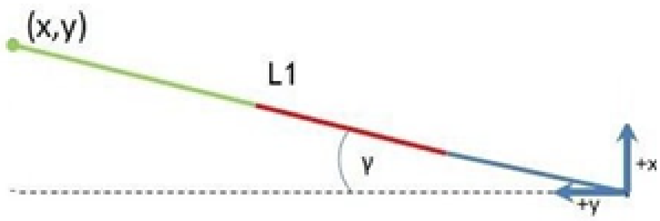

Fig -4: Inverse kinematics top view

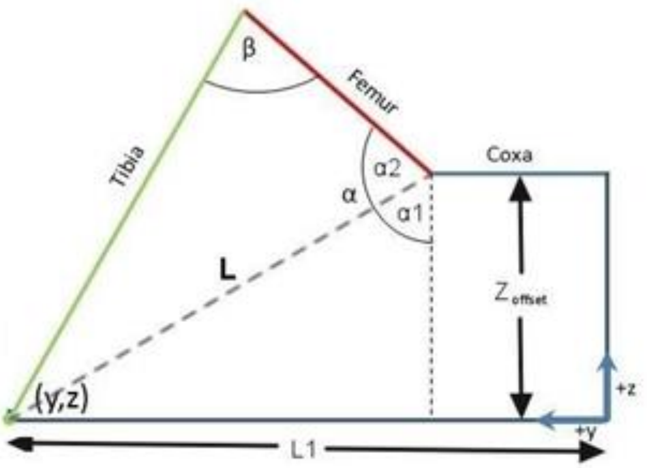

Fig -5: Inverse kinematics side view

$$\frac{x}{y} = \tan(\gamma)$$

$$\rightarrow \gamma = \tan^{-1}\left(\frac{x}{y}\right)$$

$$L = \sqrt[2]{z_{offset}^2 + (L1 - coxa)^2}$$

$$\alpha_1 = \cos^{-1}\left(\frac{z_{offset}}{L}\right)$$

$$Tibia^2 = Femur^2 + L^2 - 2(Femur)(L)\cos(\alpha_2)$$

$$\rightarrow \alpha_2 = \cos^{-1}\frac{Tibia^2 - Femur^2 - L^2}{-2(Femur)(L)}$$

$$\alpha = \alpha_1 + \alpha_2$$

$$\alpha = \cos^{-1}\left(\frac{z_{offset}}{L}\right) + \cos^{-1}\frac{Tibia^2 - Femur^2 - L^2}{-2(Femur)(L)}$$

$$L^2 = Tibia^2 + Femur^2 - 2(Tibia)(Femur)\cos(\beta)$$

$$\rightarrow \beta = \cos^{-1}\frac{L^2 - Tibia^2 - Femur^2}{-2(Tibia)(Femur)}$$

IV. INTEGRATING VACUUM SUCTION CUPS [15]

Vacuum switches and pressure gauges are normally selected on the basis of the functions required in the application and on the switching frequency.

Weight Estimations

It is an important to know the mass of the work-piece to be handled. Work-piece weight can be estimated as follows:

1. Suction Pad Mass m [kg]: m = L x B x H x ρ

a. L = length [m]

b. B = width [m]

c. H = height [m]

d. ρ = density [kg/m3]

2. Example: m = 2.5 x 1.25 x 0.0025 x 7850 Workpiece mass, m = 61.33 kg

3. Load case I: horizontal suction pads, vertical force against the workpiece load

a. FTH = Force for theoretical holding [N]

b. m = mass [kg]

c. g = acceleration due to gravitational force [9.81 m/s2]

d. a = system acceleration [m/s2] (remember to include the "emergency off" situation!)

e. S = safety factor (minimum value 1.5; for critical inhomogeneous or porous materials or rough surfaces 2.0 or higher)

The suction pads are placed on a horizontal with work piece which is to be moved sideways. Fig 6: Suction Pads

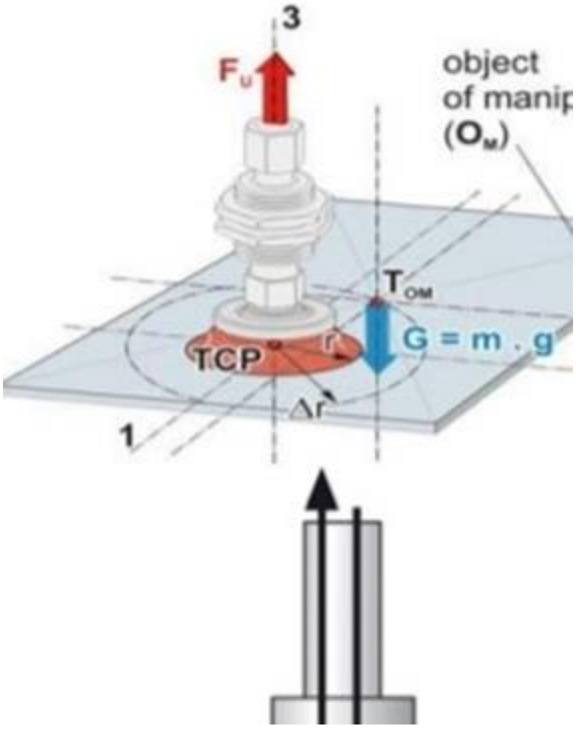

Fig 6 Suction Pads

Fig 7 Sucction pads implementation. ELECTRONIC SYSTEM

In order to control the robot there must be some control unit. Ardiuno Mega was chosen to drive the servomotors and sensors on this robot. All servo motors and sensor are connected to it. The whole scheme is in Figure 10.

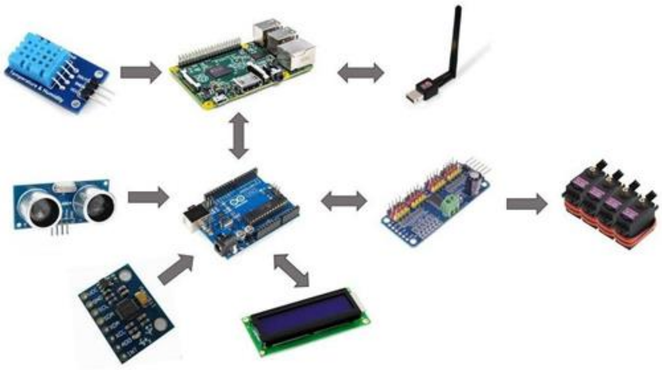

Fig -8: The electronic system of the robot.

Fig – 9 12V DC 8L/m Mini Vacuum Pump

V. RESULTS

The overall body looks like Fig -10 without vacuum integration.

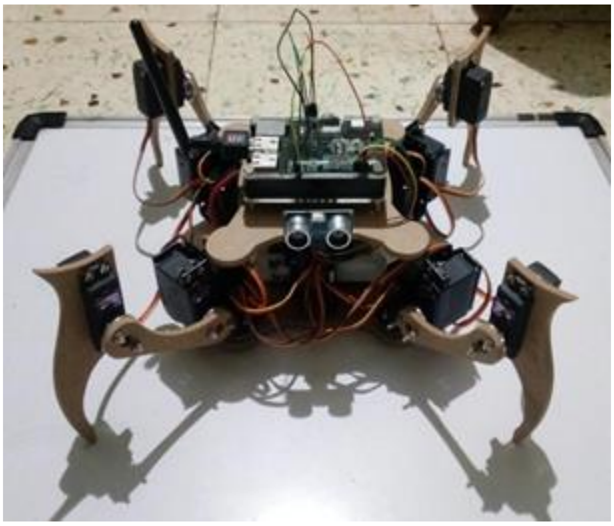

Fig 10 : The Complete robot without vacuum integrated.

VI. CONCLUSION

I would like to conclude this paper with a four-legged spider robot with three degrees of freedom for each leg was designed and capable of walking over the vertical surface of glass using vacuum suction pads. Using this prototype, one can further modify to integrate cleaning system to fulfill the main motivation of this design.

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