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Spider Robot for Façade Cleaning

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Abstract: Most skyscrapers require their glass windows to be cleaned not only on the inside but on the outside as well since dust, rains, birds, etc. can cause stains on them. This cleaning process is often carried out by people who dangle from the top of the building using a rope and carry liquid soap and other cleaning equipment required to manually clean all the windows. Not only is this operation extremely time consuming, but it is also highly dangerous. The proposed work aims at automating this cleaning operation using a spider-like robot. The body of the robot is made of two octagonal plates with six legs at six vertices, each having a degree of freedom of three and a suction cup at its end. The remaining two vertices can have cleaning arms and the bottom of the robot consists of a rotating cleaner. Cleaning resources like water and soap are placed in-between the two plates. The robot climbs the wall due to the suction provided by the hydraulic force of steam at high pressure which is controlled and programmed using the Robotic Operating System. Six legs of the robot which comprise of eighteen double shaft NEMA-17 motors are controlled using Arduino Mega and are synchronized using ROS. The tripod gait mechanism is used to move forward and pressurized steam is used to provide the suction required to hold on to the wall. This robot can be extended to perform other applications like painting a wall, or can be used in an industry to detect any gas leak or perform any assembly and transport operations.

Keywords*: *Hexapod, Hydraulic force, Legged mechanism, Spider-like robot

I. INTRODUCTION

Window cleaning is the process of cleaning the glass on the exterior of skyscrapers and architectural buildings. This process is being done manually up to this date, even on the world's tallest building, Burj Khalifa, in Dubai. Many techniques are used to perform this task like supported scaffolding, which is a raised temporary platform built on the ground for workers to stand on. Supported scaffolding is a relatively safer technique compared to aerial work platforms like a platform suspended from the roof of the building or a Boatswain's chair [1]. Most buildings are not willing to set up a temporary platform to clean windows since suspended platforms are much more mobile and can enable larger areas to be cleaned in shorter periods. Suspended platforms are also cheaper compared to a temporary platform being setup. Such aerial work platforms endanger the lives of several workers every year, which can be avoided if the task of window cleaning is automated [3]. The proposed cleaning spider robot assists in automating the task of window cleaning. The robot's body is made of two octagonal plates, separated by the C-shaped joints attached to each of the six legs of the robot. Only six out of eight edges are used for the legs of the spider. The remaining two, opposite corners, can be used to attach grippers, which can be
used as a safety measure to grip onto the wall incase suctionfails. Another possibility is to attach robotic arms to the empty edges to extend the robot's application to serve as a wall painting robot or a pick-and-place robot. Every leg of therobot has its degree of freedom as three, which is provided by the double shaft motors used at every joint of the leg. The end effector used at each leg is a suction cup that forms the foundation for the robot's movement. At any given point of time, the robot requires only three legs to remain on the ground for it to be stable [4].
The stable condition is achieved by the careful coordination between the different legs of the spider using different microcontrollers and various algorithms. Before the robot climbs the wall, it first detects the type of wall it is climbing using image processing and machine learning. If there are cracks in the wall, the robot does not climb it since suction fails in this condition [5].

Window cleaners generally use various kinds of cleaning tools like Chamois and scrim, water, and squeegee and water-fed poles depending on the type of dirt they want to clean. The robot stores the cleaning liquid and water in between the two octagonal plates along with the heating element, and the pipes connecting to the suction cups originate from here. The cleaning fluid is dispensed to the cleaning roller, which is attached to the bottom of the robot. This roller rotates and simultaneously dispenses the liquid, thereby cleaning that portion of the wall. Communication between the ground and the robot can be established via Bluetooth or Wi-Fi, depending on the height of the building. The HC-05 Bluetooth module has been used for communication in this robot.

II. RELATED WORK

The study on the automation of façade cleaning is an ongoing process, with constant developments. One such study proposed a machine that used one slider, which was attached to the top of the building, and another slider that had a vacuum cleaner with the suction cups to attach itself to the wall. The second slider was tethered down from the wall and controlled using an AC motor. Such a machine might not besuitable for buildings of all widths since the length of the slider plays a significant role in cleaning the entire building efficiently [1].

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Another study introduces a tethered guiding vehicle system (TGV) used to carry a commercial robot. The TGV controls the robot's movement, and the robot performs the cleaning operation. A detailed study on the kinematics of the TGV results in gravity as a parameter, the minimum force used to hold the robot on the rope, the friction force and finally the force needed to move the robot in both upward and downward directions [2].

The cost factor has played a significant role in another study, which introduces a semi-automatic robot for façade cleaning. It comprises an intelligent carrier system that takes the uneven surfaces of the building into consideration, which is a factor often overlooked. The cleaning mechanism uses a unique sealing method, which prevents water from dripping down. This study, however, assumes that the carrier tether is always attached to the building, which isn't feasible since most buildings require cleaning only twice a year, and this installation could add to the cost of the setup [3]. Dario Delgado Esteban introduces the concept of stability to enable the locomotion of the robot. After the stability margin and longitudinal stability margin is considered in the design of the robot, it moves using tripod gait [4].The performance of a hexapod robot is determined by stride length and frequency, which are results of movement using tripod gait. The base joint, which connects the body of the robot with the coxa, is responsible for the stride length. The increase in frequency increases the cylinder forces due to an increased impact between foot and terrain [5].Another study proposes the use of a hydraulic mechanism for the movement of the robot. The hydraulic system consisted of the power part, which used a gasoline engine to drive the pump and a servo part that controlled the flow of hydraulic oil [6].A study by Saranya R proposes a technique to make the robot walk using PWM signals generated by the Atmega microcontroller. The microcontroller on the robot communicates with the Host Computer using the RS232 interface. The microcontroller generates an 18 channel PWM signal to control all the 18 motors used to move the robot [7].Another study on the walking of the hexapod spider uses the 'Follow-the-contact-point' gait algorithm, an event-driven algorithm consisting of four nodes. This study also explores the possibility of changing the stride length when an obstacle is encountered, thereby making it a versatile model [8]. The alternative methods for the locomotion of a spider robot is demonstrated in a study by Takuma Nemoto. The method of rolling locomotion which is implemented by a wheeled spider is most suited for horizontal surfaces. The force of gravity, being much more than the force of friction makes it unsuitable for vertical surfaces like the façade of a building [9]. In a study conducted by Chao Sun, the spider robot is designed by considering the biological characteristics of a spider. A careful study on the bionic perspective enables the design of the trunk and legs with suitable materials to build an optimized spider robot [10]. Mitsuru Taniwaki presents a study on an alternative navigation method for the spider robot. In order to reduce the weight and complexity of the robot, four air flow sensors are used to detect the direction of the wind. This method is extremely useful in open areas with no access to GPS or any other navigation techniques. The four air flow sensors are used to control the motors used in the robot [11]. The robot designed by Jong Hyung Kim uses a solar battery as backup power source. This reduces the number of batteries that need to be carried and thereby reduces the weight of the robot [12]. The direct kinematics of velocity and position of a hexapod robot was calculated. The position and the angular velocity calculated was of the body and legs of the robot. This is done by assuming specific time variations for all joint variables.[13]. In contrast to this, a geometrical method is used to calculate the inverse kinematic of a robot. This study uses the known leg joint velocities to calculate the position of the robot [14]. In a study by Vitthal B. Jagtap, a gravity search algorithm is used to control the stability of the robot. The robot moves forward using tripod gait until an obstacle is encountered. The robot switches over to the wave gait mechanism till it crosses the obstacle [15].

Mantis, one of the first commercially available robots is built on the basic concept of high stability. Most insects can climb steep surfaces because of their low center of mass. Similarly, the robot is also designed to have a low center of mass to achieve the required high stability. The robot is designed with the legs having six DOF and grippers are used at the end of each feet [16].

III. ROBOT DESIGN

A) Body Design of the Spider Robot

The robot's body holds the cleaning equipment along with providing a stable platform for movement. An octagonal shape is chosen for the robot's body instead of a rectangle shaped body. The octagon shape allows a spacing between the legs and enables the movement of the leg in a much wider angle. This shape also avoids collision between consecutive legs of the spider, which wouldn't have been the case if the spider robot had a rectangular shaped body. This shape also distributes the weight equally on either side of the robot thereby making it more optimally stable.

Two octagon-shaped platforms are placed with a gap in between them, such that the leg of the spider can be attached between them as shown in figure 1. These two octagonal plates were made using Carbon fiber to ensure that it is lightweight yet sturdy.

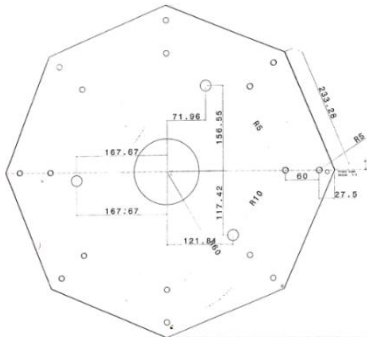


Figure 1. Body of the spider robot

A dome placed over this platform stores the cleaning equipment and is provided with three openings to insert bottles of water and soap, as shown in figure 2.

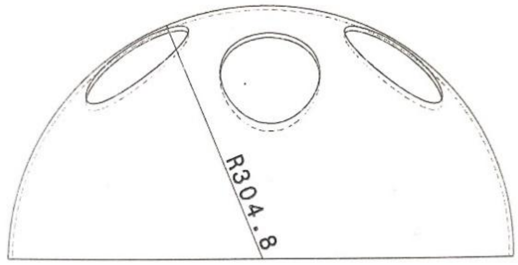


Figure 2. Dome to store cleaning equipment

B) Design of the spider robot's leg structure

A spider's leg can be categorized into eight significant parts. For simplification, we construct the robot's leg only using four of these parts, namely, the coxa, femur, tibia, and tarsus. The robot's leg provides three degrees of freedom.

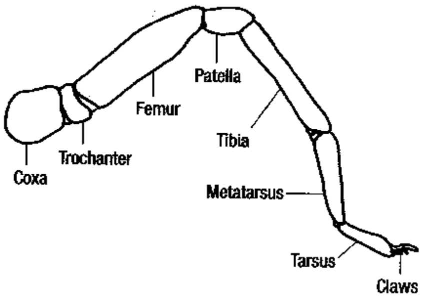
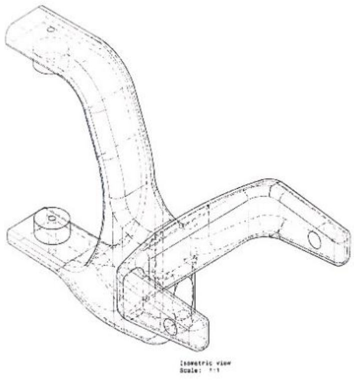


Figure 3. Leg structure of a spider

[Source: https://havoc20.wordpress.com/2010/11/13/spider-leg-structure/]

The body of the robot is connected to the leg through the base joint or hip joint, called coxa, as shown in figure 4.



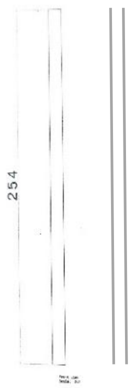
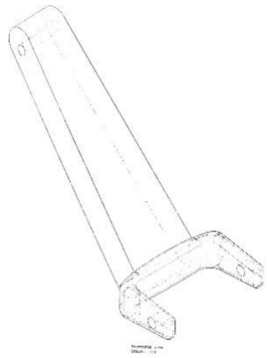


Figure 4. Coxa **Figure 5. Femur**

The coxa is responsible for the roll of the robot's leg. The coxa is then connected to the femur through a NEMA 17 dual shaft motor, which provides the yaw to the leg, which is shown in figure 5. To move the leg up and down, we connect the femur to the tibia, which is, in turn connected to the suction cup, which works as the tarsus. The tibia and the femur form the knee joint of the robot's leg. Aluminum Alloy is used to make the coxa, femur and tibia. Rubber is used to make the suction cups to ensure a secure fit to the façade wall.



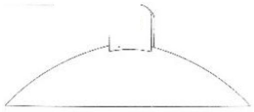


Figure 6. Tibia **Figure 7. Tarsus**

The dimensions of all the four parts are summarized in the table below.

Table 1. Dimensions of the leg structure.

Leg Part	Dimension (in mm)
Coxa	186 x 237
Femur	254
Tibia	186x285
Tarsus	140

The six legs of the spider are attached to the three opposite sets of edges of the octagon. The other two opposite corners are left empty to attach the cleaner handle or any other equipment to extend the robot's application. The robot has a total of eighteen NEMA-17 double shaft motors.

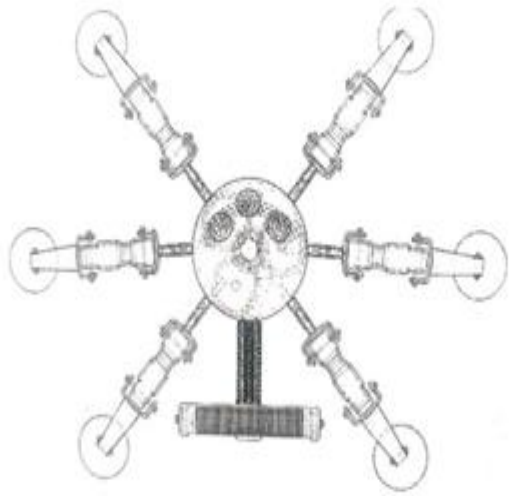


Figure 8. Complete design of the Spider robot

IV. METHODOLOGY

A three-step procedure is involved in moving the robot's leg. First, the tibia and tarsus are lifted off the ground. The coxa is then tilted to the angle required, after which the femur is moved left or right, depending on whether the robot has to move forward or backward, respectively. A hydraulicmechanism has been used to enable the robot to climb walls and perform cleaning operations. The water used for cleaning the walls is also used for suction.

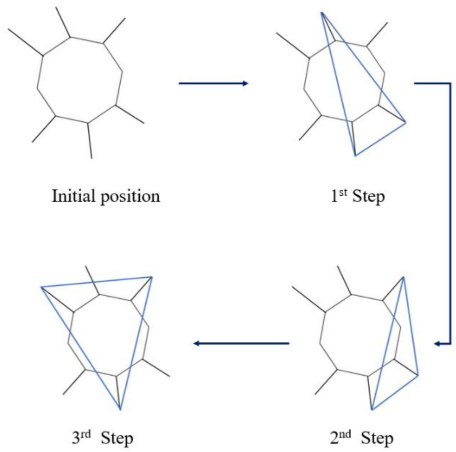


Figure 9. Order of legs transfer in tripod gait-based locomotion

The water is converted to steam using the SparkFun Arduino Pro Mini 328 heating element. This is done to kill germs, decrease the amount of water required, and thereby reduce the weight of the robot. The pressurized steam is sent through transparent tubes to each suction cup when that leg is needed to move. The bottom of the robot's body is attached with a sealed roller, so when the robot moves on the façade, the steam can clean it even if there is no cleaning trunk attached. The water used for suction and cleaning can be recycled.

V. RESULTS AND DISCUSSION

A prototype based on the above-discussed design has been constructed, as shown in figure 10.

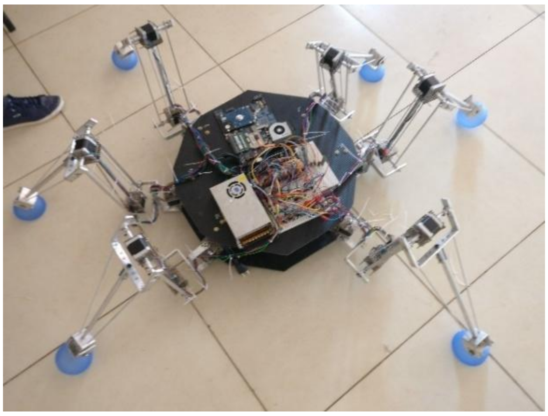


Figure 10. The prototype of Spider Robot for Façade Cleaning

The robot uses the tripod gait to mechanism to move forward. The cleaning arm of the robot can clean an area of 30 cm^2 in 10 seconds. To improve the robot's performance in situations where it encounters an obstacle, the wave gait mechanism can be used till the robot causes the obstacle or any other uneven surface. A comparison between this robot and previously existing robots have been made in Table 2.

Table 2. Comparison between related and proposed work.

Related Work	Proposed Work
The façade cleaning robots required a temporary setup at the top of the building to support the robot [1][2][3].	This cleaning spider robot does not require any previous setup thereby making it cost effective and fast.
The tripod gait and wave gait mechanisms have been used for the forward motion of the robot [15].	Since a façade is usually a levelled surface, only tripod gait mechanism has been used, which reduces the complexity of the robot.
Few existing robots made use of wheels for movement due to which the robot cannot move forward on steep surfaces [9].	This spider robot uses suction cups as the gripper to enable movement in both, horizontal and vertical surfaces.
For the hydraulic mechanism, hydraulic oil was used, which is heavier than water and increases the total weight carried by the robot [6]	Instead of hydraulic oil, water which is converted to steam is used to implement the hydraulic mechanism. This reduces the weight of the robot and a small amount of water can be used to clean a relatively larger area.

VI. CONCLUSION

This design of the robot highlights the possibility of numerous extensions of the same model. The cleaning operation can be replaced by painting as an alternative application. This paper also highlights the advantage of steam cleaning techniques over brush cleaning techniques, thereby making it possible to use these robots in hospitals or labs, where clean rooms are essential. Gas sensors can be attached to these robots to make them useful in chemical industries to detect a gas leak while performing other operations like inventory management.

To make the robot more efficient, a high-quality camera which can detect very minute particles can be attached to the robot. A Convolutional Neural Network can be used to predict whether a particular area needs to be cleaned. Using transfer learning, the model can be trained using MobileNet architecture so that it is fast and requires less memory.

It can be concluded that the robot designed on CATIA has been implemented by providing numerous possibilities for the extension of the same robot for façade cleaning and various other applications.

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