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Trajectory Planning of a Hexapod Robotic Kit

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***Abstract*—** Mode of locomotion of a robot can be chosen according to the condition of the terrain; these are wheeled, Legged and Crawler or Hybrid. Legged mobile robots are superior to conventional wheeled mobile robot (WMR) for rough and marshy terrain due to its terrain adaptability. They have also the ability to raise or lower bodies or tilt them by varying the length of its legs by bending knees. However, unlike WMR, legged robots are much complex and needs more comprehensive analysis for developing a realistic autonomous system. The goal of this research is to develop a path planning of powered and autonomous hexapod robotic kit which is capable of navigating different terrain within the mechanical motion limits. It has been observed that the kit is capable to take turn at sharp corner or when it needs to turn at a large angle at any instant.

***Keywords*—**Legged robots, Trajectory planning, Wheeled mobile robot.

I. INTRODUCTION

The legged robot can walk on more complex terrain even on the rough terrain not suitable for wheeled or tracked robot due to its flexible legs. The difficulties associated with gait selection depend on many factors like the terrain condition, the mobility of the vehicle, stability requirement, degree of control, power requirements, etc. The number of legs of walking robot not only depends on the power requirement and mobility, but it also contributes stability margin to ensure stable movement of the walking machine. Generally, more number of legs generates more stable walking gait. It also increases the ability to navigate more complex terrain. However, the increased number of leg increases the number of controllable actuators and power requirement. Many research works have suggested earlier the optimized number of leg of walking robot considering the different walking condition and different requirement.

With the intention of reducing the number of controllable actuators, M Kaneko et al developed three walking machines namely: MELWALK – Mark I, MELWALK – Mark II and MELWALK – Mark III [1]. Mark I had one DOF so it could move only in straight backward or forward. Mark II was capable of two-dimensional motion. Mark III was with additional vertical degree of freedom per leg using straight-line mechanism. Adaptive Suspension Vehicle o ASV project was initiated in 1982 to address the shortcomings of the earlier designs. It consisted of six three-dimensional pantograph legs with lateral symmetry. In 1987, S. Azarm et al. developed a six legged walking machine TERRAPIN I [2]. It was composed of three parts: body, legs and controls. The body is a tripod design in which one of the two set of three legs is always on the ground. The legs are modeled after a pantograph and are driven by “acme” screws in both horizontal and vertical directions. In 1991, R. Patrick et el. along with the student of Mechanical and Electrical Engineering designed a crank-and-rocker driven pantograph leg mechanism. This leg was used in University of Maryland’s walking robot. The role of traditional four-bar mechanism is reversed and coupler curved used as a transmission link. AMBLER was developed by CMU Planetary Rover Project for autonomous navigation in unknown rough terrain. The legs of AMBLER decouples horizontal and vertical motion with their orthogonal rotational-prismatic-prismatic mechanism. This was useful in minimizing the power consumption and simplifying motion planning. MECANT (MECanical ANT) was a hydraulic combustion engine driven six-legged machine. Two dimensional pantograph legs were chosen because of its controllability and energy efficiency. In order to increase the maneuverability and stability, a third DOF was selected to rotate the leg about vertical axis. It carried all the computer power needed and was independent from external energy sources. In 1999, Marc Poe developed a six legged walking machine called HANNIBAL. The design of HANNIBAL was borrowed from the anatomy of spiders.

In Recent past, many techniques of trajectory planning for the walking robot have been suggested. Spring Loaded Inverted Pendulum (SLIP) characteristic of running animals is followed in the trajectory planning of a compliant leg hexapod robot, called RHex [3]. It exhibits a dynamical gait called “bouncing”. RHEX capable to travel more than one body length per second over terrain. S. Zhang et al proposed a composite CoG trajectory planning algorithm associated with a new mode of CoG trajectory generation which enhanced the efficiency and the stability a quadruped robot [4]. The CoG trajectory has been generated automatically according to the foothold pattern in real time. K. Hauser et al designed of a motion planner that enables legged robots with many degrees of freedom to navigate rough, irregular terrain [5]. They applied the planner into six-legged Lunar vehicle, called ATHLETE, and the a humanoid robot HRP-2.

Another autonomous navigation framework has been proposed which has two main devisions: traversability estimation of the terrain and path planning [6]. The traversability is estimated by applying filters to a discrete elevation map of the terrain. Again the traversability values has been estimated for path planning to overcome obstacles such as steps, gaps, and locally steep and rough terrain.
In this work, the trajectory planning algorithms for trajectory generation of hexapod walking robotic kit are proposed for navigating different nature of leveled path within the mechanical motion limits. Sensory system and algorithm are designed to enable the robotic kit for taking turn at sharp corner or when it needs to turn at a large angle at any instant.

II. METHODOLOGY

Any walking robot has few salient features which make the system more versatile and easy to control [7], these are:

- With the ability to rotate at any desired angle at any point
- With the ability to take turn at any desired curved path
- With the ability to walk in any direction (strafe) and rotate, at the same time if needed
- That is power and control autonomous

An automated moving vehicle can sense, make decision intelligently and move accordingly. Hence, it should have sensing elements, called sensors, to make aware about the environment, a microcontroller to make logical decision and actuator(s) equipped with mechanical parts to make it able to navigate. The microcontroller makes judgment based on the rules fed in the form of logical program.

The infrared light emitting diodes (IR-LED) and IR detectors have been considered here as sensor for this kit which is similar to what would be finding in any home appliances like television, set-up box, air conditioner, etc. and its handheld Remote. These two components can be used together to perform for object detection, proximity detection, wireless communication, etc. Fig. 1 shows the scheme of the IR-LED detection system where BASIC Stamp I/O pin P7 is used to send signals out the IR-LED and P8 is used to read the 40 kHz IR detector’s output with a 50% duty cycle.

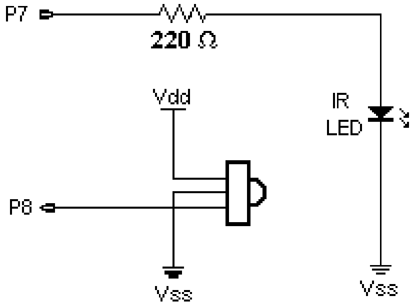

Figure 1. Schematic of the IR-LED detection system

This is a very low cost sensor whose range of sensing can change easily by changing the circuit resistance. The range can be maximize by lowering the circuit resistance value and vice-versa. Arduino Mega 2560 microcontroller board has been considered along with necessary components where ATmega 2560 is used as microcontroller in this board and power was taken from an external source of 5V DC through USB connection. HSR-5995TG coreless digital servo motors of rating torque = 34.0 kg-cm have been selected as actuators. The servo has titanium gears for high strength and tight meshing. Brass bushing for servo gear shafts fitted on upper case offers long life and smooth operation of the servo.

III. MATHEMATICAL MODELLING

One stride would be completed in two equal steps as the wave gait pattern is chosen for this hexapod robotic kit. The wave gait [8] is chosen as it is popular, simple and well suited for a walking machine moves slowly in straight path. When one set of legs (three pantograph legs) of the robot swings in the air, the centre of gravity of the robot moves at a uniform speed in the direction of movement of other set of legs (remaining three) on ground and pushing the body in forward. The mechanical design of the vehicle has been taken in separate paper of the author. The necessary parameters of mechanical design are recalled here as follows: The radial distance of sensors from the body centre is 300 mm, stroke length of vehicle is 100 mm, and sensing range of sensor is 0 to 125 mm. Therefore, total sensing distance from the centre vehicle is 425 mm in the direction of sensor placed.

Let α_n is the angular position of sensor with respect to the direction of movement. The sensing point of each sensor is defined by S_n and these points are making the angle (α_n) of -60°, - 30°, 0°, 30° and 60° respectively with forward direction as shown in Figure 2.

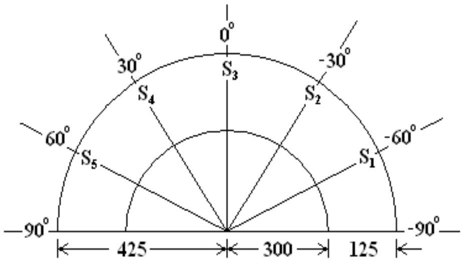

Figure 2. Position of different sensing points

Therefore, S_n can be determined using the formula

$$S_n = \{(425\sin[\alpha_n]),(425\cos[\alpha_n])\} \quad ..(1)$$

where, α_n is the angular position of sensor.

The extreme sensing positions corresponding to different sensors are determined from the above equation as follows:

$$S_1 = (368.06, 212.5) \quad ..(2)$$

$$S_2 = (212.5, 368.06) \quad ..(3)$$

$$S_3 = (0, 425) \quad ..(4)$$

$$S_4 = (-212.5, 368.06) \quad ..(5)$$

$$S_5 = (-368.06, 212.5) \quad ..(6)$$

If the body centre is at the point, $C = (X_c, Y_c)$, therefore, the sensing position with respect to a reference point is

$$S_n = (X_n, Y_n) = \{(X_c + 425\sin[\beta_n]),(Y_c + 425\cos[\beta_n])\} \quad ..(7)$$

where, $\beta_n = (\alpha_n + \theta)$ = total angular deflection and θ = total angle of twist from the initial position.

The distance of each sensor from the reference point is

$$r_n = \sqrt{[X_n^2 + Y_n^2]} \quad ..(8)$$

Let the permissible range of distance of sensors is $R_1 < r_n < R_2$. Then, there are three conditions according to which the body will further move:

i). If $R_1 < r_n < R_2$, body will follow the straight forward movement.

ii). If $r_n \le R_1$, body will take a turn in positive angle with respect to centre.

iii). If $r_n \ge R_2$, body will take a turn in negative angle with respect to centre.

Accordingly, the new positions of the centre or sensors for next steps can be calculated as

$$(X_n, Y_n) = \{[X_{n-1} + n(100.\sin\theta)],[Y_{n-1} + n(100.\cos\theta)]\} \quad ..(9)$$

where, n = no. of step at that particular direction, (X_{n-1}, Y_{n-1}) = the initial position on that particular direction and (X_n, Y_n) = final or determined position.

IV. SIMULATION AND RESULTS

For trajectory planning, a curved path is considered having general equation of, $Y = a_i(x^4 - c_i.x^2) - b_i$ ..(10)

where a_i and c_i is constant depends upon the nature of curve (path) and b_i is the offset of starting point along x-direction from a reference point for a particular curve. Therefore, the two outer lane of the path can be defined as follows:

$$y = a_1(x^4 - c_1.x^2) - b_1 \quad ..(11)$$

and $y = a_2(x^4 - c_2.x^2) - b_2$ ..(12)

If, the shortest distance of any sensor from the outer lane or any object is designated by d_i, then two parameters concerned to boundary condition, i.e. d_1 and d_2, can be defined from the equation (11) & (12) as follows:

$$d_1 = a_1(x^4 - c_1.x^2) - b_1 - y \quad ..(13)$$

and $d_2 = a_2(x^4 - c_2.x^2) - b_2 - y$ ..(14)

From the above boundary conditions, it can be written that if $d_1 > 0$ and $d_2 < 0$ or $d_1 < 0$ and $d_2 > 0$, body will follow the straight forward movement. Otherwise the body will take a turn in an angle with respect to centre according to the condition of sensor signal. The trajectory planning of the hexapod robotic kit in a curved path is shown in Fig. 3.

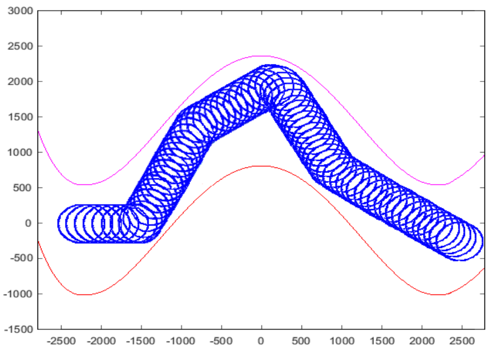

Figure 3. Simulated path trajectories on a curved (spline) path

The motion planning has been simulated at MATLAB Sim-mechanics platform to visualize its movement. Similarly, a trajectory has been planned for a square path as shown in Fig. 4. From the trajectory of square path it can be seen that the robotic kits is capable to take turn at sharp corners efficiently.

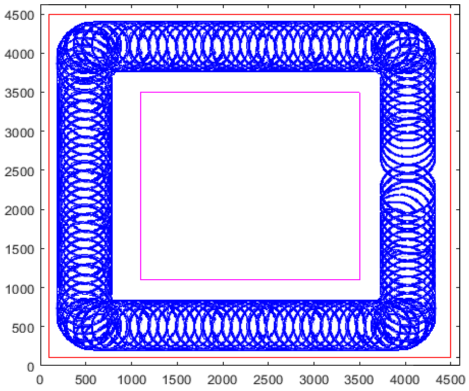

Figure 4. Simulated path trajectories on a square path

V. CONCLUSION AND FUTURE SCOPE

The path planning technique of a powered and autonomous hexapod robotic kit is proposed here for navigating different terrain within the mechanical motion limits. Sensory system and algorithm has been designed in such a manner that it enable the robotic kit to take turn at sharp corner or when it needs to turn at a large angle at any instant. The above work primarily explores the path planning technique considering the level terrain. However, further effort can be made to design the path planning considering uneven terrain. The path planning strategy can also be applied to quadruped or octopod robot with suitable modifications.

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Authors Profile

H Masum received the B.E. degree in Mechanical Engineering from VTU, Belgaum, India in 2005 and M.Tech. degree in Production & Design Engineering under Mechanical Engineering from NIT, Durgapur, WB, India in 2007. During 2007-2013, he worked as Sr. Engineer in M.N. Dastur & Co. (P.) Ltd., Kolkata, India, to design various units of steel plants, power plants and ferro-alloy plants for many nations. He has submitted his Ph.D. thesis entitled "Intelligent Active Ankle Foot Prosthesis Using Multisensory Feedback" in October 2018 at Indian Institute of Engineering Science and Technology (IIEST), Shibpur, Howrah, India since 2010. He is also with Ghani Khan Choudhury Institute of Engineering and Technology, Malda (Centrally Funded Technical Institute under Ministry of HRD, Govt. of India) as Assistant Professor and Head, Dept. of Mechanical Engineering.