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Dynamic Balance Control of Legged Wheeled Robot

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Abstract

In this paper, a legged wheel robot that is able to manipulate its four legs while in motion in order to control its roll and pitch, is discussed. The robot is modeled, and an input signal is given as displacement to the wheels. The orientation of the chassis is used in negative feedback to assure stability by carefully manipulating the legs of the robot. Both the active and passive cases are compared and the advantage of using such a system is illustrated.

Keywords: Legged wheeled robot, Unmanned Ground Vehicle, self- stabilizing platform, articulated-wheel suspension.

INTRODUCTION

The disciple of field robotics has witnessed an exponential growth for the past few decades .With the first expedition of Lunokhod 1 in 1969 by the erstwhile Soviet Russia to the NASA‘s Curiosity Mars Rover launched in 2011; field robots have completely replaced man in the area of space exploration. Robotic vehicles are also found to be of immense help in hostile situations or for military applications. As these robots are bound to encounter uneven and rugged terrain, the aim is to design and simulate a legged-wheeled robot that while in motion, caliberates its arms to compensate for the roll and pitch so as to keep the chassis steady. Thanks to the advances in control systems, a negative feedback control is developed. Any pitching or rolling induced by the terrain is considered as an error in the system, and appropriate input signal is given to the servo revolute joint in the legs.

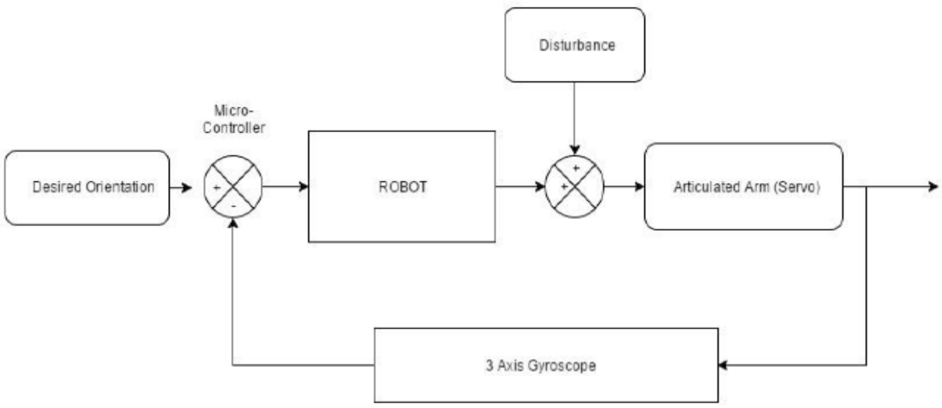

Figure 1: Control flow diagram of the proposed robotic system

LITERATURE REVIEW

A great deal of research has been carried out by creating simulation models and experimentally verifying the same for the balance control of two-wheeled self-balancing robot. Prototypes have been created for self-balancing of a single wheel robot using gyroscope as well [1]. Usually the control strategy involves the use of PID (Proportional Integration

Derivative), Fuzzy [2] [3] or Linear-quadratic regulator (LQR). Wei An and Yangmin Li [4] demonstrated a Proportional-integral-derivative (PID) and Linear-quadratic regulator (LQR) to control a two wheeled robot. On the experimental side, a single axis gyrcoscope and 2-axis accelerometer have been used to control a two wheeled robot using PID and LQR based PI-PD control and found that the self-balancing Is best achieved in the vicinity of upright position [5]. Kiyotaka Kawashima et al. [6] presented a novel rolling stability control based on two degree of freedom controller which was intended at improving the ride quality in addition to safety. A hybrid suspension consisting of wheels and links controlled by actuators are also popular and useful in various tasks. Kawee Suwannasit and Sathaporn Laksanacharoen designed a bio-inspired hybrid leg-wheel robot where each leg consisting of six-bar and four-bar linkages to push it forward or backward [7].

Articulated robots are robots containing spherical joints that can manipulate their respective links to enable manipulation in their workspace. Some of these articulated robots are fitted with wheels to enable it to move freely in the workspace or to assist in exploration like in the case of Mars rovers [8][9]. Such articulated robot with omni and hemispherical wheels has been used for inspecting and exploring winding pipes [10]. Wenwei Wang et al. [11] discussed about the stability of four articulated wheels using single track analytical linear model for a deep insight into dynamic yaw performance. Sahand Ghaffari and Mohammad Reza Homaeinezhad [12] demonstrated control of eight wheeled with nonholonomic constraints by adjusting articulating angles. Simultaneously, Wheel-legged that could optimize the traction the traction force and the tipover stability [13]. New active electrical servo based suspension systems have been demonstrated under laboratory or experimental conditions for exploration vehicles but has been largely limited to roll stability. Fewer research has been done is stabilizing both roll and pitch, which has been discussed in this paper.

DESIGN AND WORKING

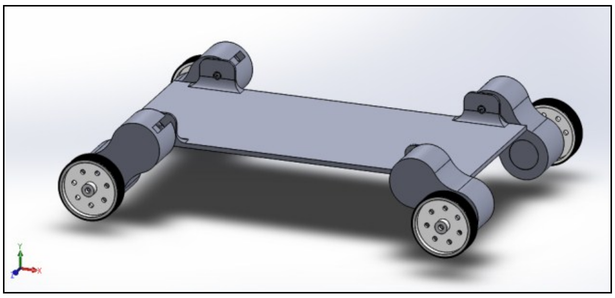

Figure 2: Proposed Design for the legged-wheeled robot

The design consists of a chassis having four legs as shown in the Fig. 2. Each leg has two slots, the upper one for fitting a servo motor while the lower one for fitting in a D.C. motor. Each servo motor will have a servo metal horn connected to its output shaft which will be screwed with the chassis. This will form a revolute joint between the chassis and the legs. So, by rotating the servo through a specific angle will cause the leg in which it is embedded to rotate accordingly. The legs can move independently of one another, which in turn will cause the chassis to pitch or roll. Alternatively, they can also be manipulated to balance any externally induced roll or pitch. By using the derived mathematical equation, these can be manipulated accordingly.

STABILITY EQUTIONS

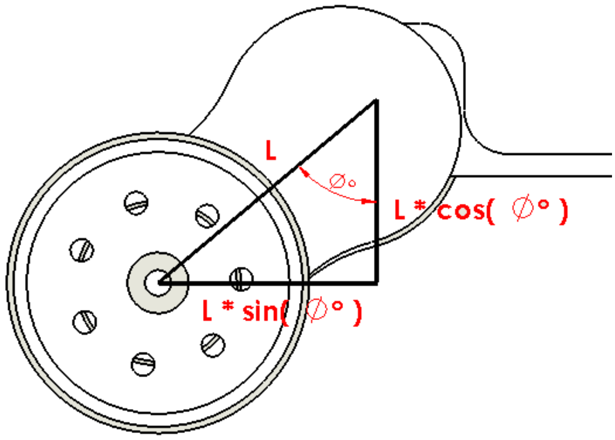

Figure 3: Legged-wheel design of the front left section of the bot. 'L' is the distance between the center of the wheel and the point of connection of the servo with the chassis. Φ is the angle made by the axis servo with the vertical axis.

Let L be the distance between the center of the wheel and the point of mounting of the servo motor attachment to the chassis. For any pitch angle α or roll angle β will cause the bot to pitch or roll respectively. In order to compensate these disturbances, the change in the servo angle θ is given as follows. Length and Breadth of the chassis are also used in the formula.

For any pitch angle α, whether positive and negative, the change in servo angle is given by

For front wheels,

$$\Theta = \cos^{-1} \{[L * \cos(\varphi) \ - \ Length * \sin(\alpha)] / L]\} - \varphi$$

For rear wheels,

$$\Theta = \varphi - \cos^{-1} \{[Length * \sin(\alpha) \ + L * \cos(\varphi)] / L]\}$$

Similarly, for any roll angle β, whether positive and negative,

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the change in servo angle is given by

For right-side wheels,

$$\Theta = \cos^{-1} \{[L * \cos(\varphi) - Breadth * \sin(\beta)] / L]\} - \varphi$$

For left-side wheels,

$$\Theta = \varphi - \cos^{-1} \{[Breadth * \sin(\beta) + L * \cos(\varphi)] / L]\}$$

PROTOTYPING

A 3D printed prototype was created using PLA for visualization using MAKERBOT Replicator 2. The infill used was 10% and diamond filling was used.

Figure 4: A 3D printed leg for the proposed robot. The upper rectangular slot is for fitting a servo motor while the lower circular slot is for fitting D.C. motor

ELECTRONICS SCHEMATICS

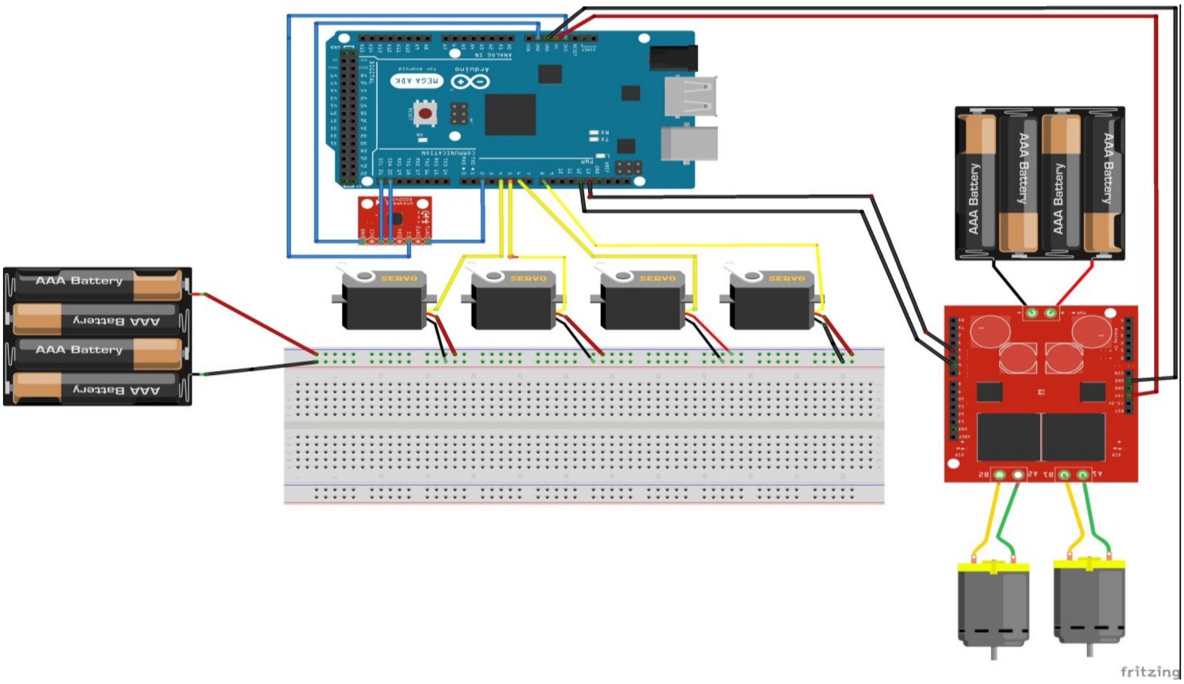

Figure 6: Electronic schematic for the proposed design.

In order to control the bot, the electronic schematic is designed as shown in the Fig. 6. Arduino Mega 2560 micro-controller board is used in this case. For controlling the 4 legs, 4 servo motors have been used. Servo motor popularly used by hobbiest has 3 pins namely signal, ground and power. The signal pins of 4 servos can be connected to the micro-controller (digital pins) while a seprate 6V D.C. power supply has to be given as the arduino will not be able to supply enough amperage to the servos. A separate power supply

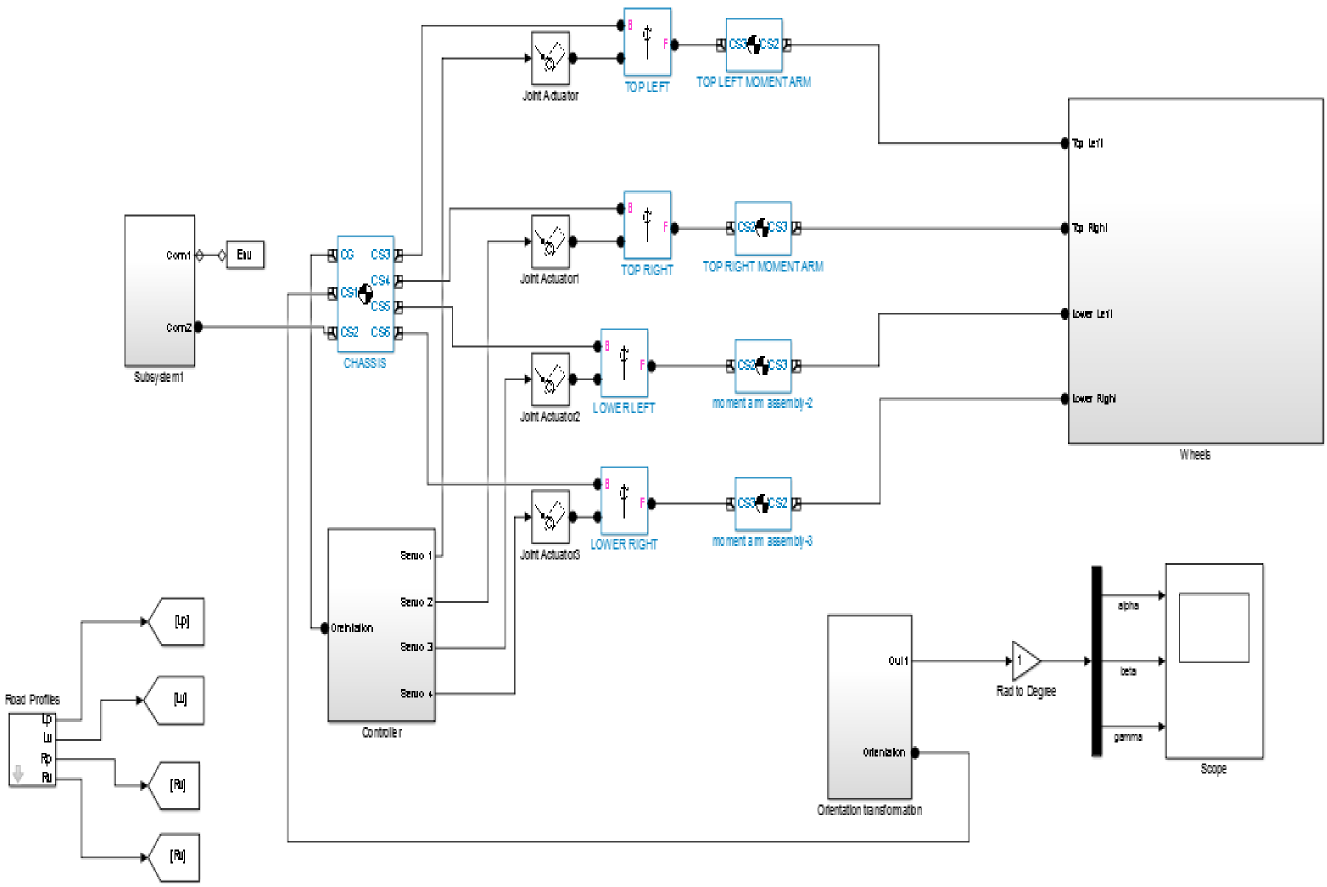

Figure 5: Simulink Model for the legged-Robot

needs to be provided for power the D.C. motors to drive the bot. To obtain the euler angles, 3 axis gyroscope and accelerometer MEMS sensors can be used like IMU (Inertia Measuring Unit) 6050 or IMU 9250 which has an additional digital compass.

SIMULATION

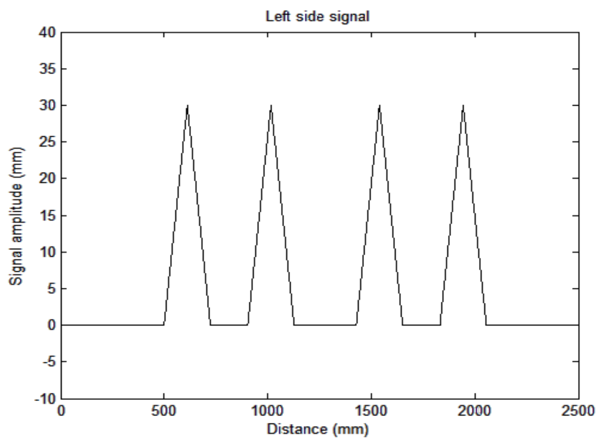

Figure 7: Input signal for left side wheels. . The X-axis is the distance travelled by the wheels. The diameter of the wheel is 0.1 m and it is given a constant angular velocity of 72 rad/s

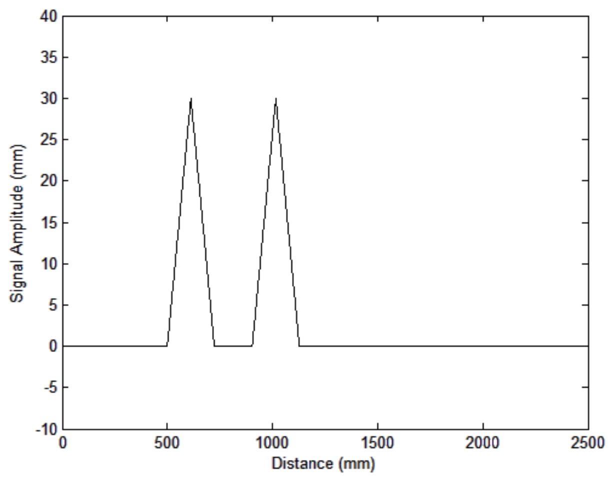

Figure 8: Input signal for Right side wheels

A triangular wave input signal is given to the left and the right wheels as shown in Fig. 7 and Fig. 8 respectively. The amplitude of the triangular wave form is 30 mm. There is a time delay of 10 sec between the front and the rear wheels. Notice that initial the two waveforms are sycronised to cause pitching while the later two wave forms given only to the left wheel will cause rolling. The input is displacement based and the force required is computed automatically. The CAD model is imported and a Simulink model is created as shown in Fig.5. The orientation of the chassis is the control parameter. We need to keep the stability matrix constant inspite of any input displacement given to the wheels. The wheel are given a constant velocity of 72 rad/s. Joint actuators are used to give input to the revolute joint in between the legs and the chassis. The oreintation matrix of the chassis is recorded using a scope.

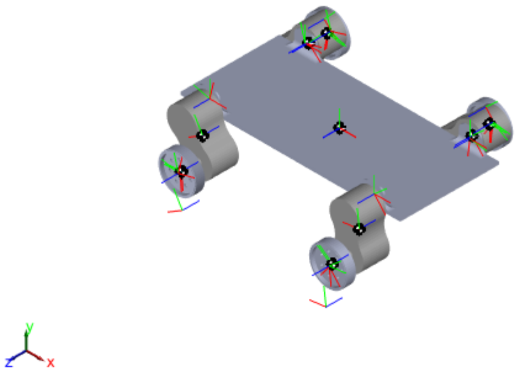

Figure 9: Model imported into Sim-Mechanics. Observe that all the legs are at different angles. The input signal is given to the wheel center along positive Y-axis as displacement.

RESULTS AND DISCUSSION

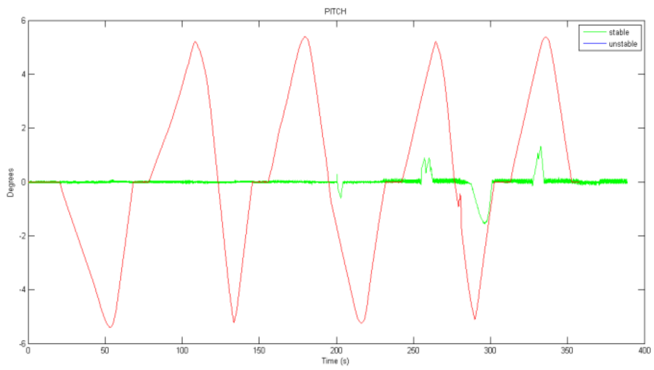

Figure 10: Pitch profile. The red color depicts the pitch when the Legs's servos are inactive while the green trend depicts the active case.

The orientation of the bot is mapped and the result in Fig. 10. clearly depicts the advantage of using such a system. The bot swings up and down when the feedback and the input to the revolute joints are disabled. The maximum pitch is 5.8 ° and the range is 9.26°. However, when the feedback is enabled and appropriate signals calculated using the derived mathematical equations, the maximum pitch is such case is -1.71 ° while the range is 2.32 ° which is much lesser than the previous case.

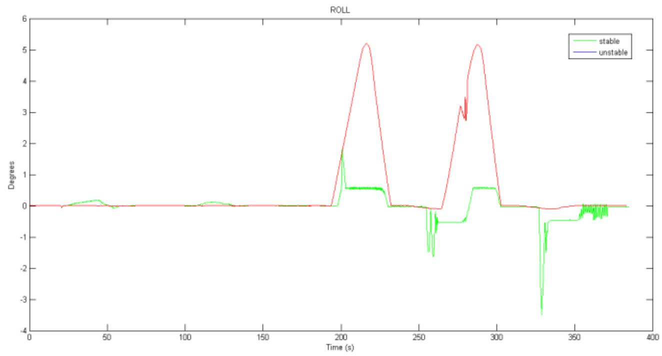

Figure 11: Roll profile. The red color depicts the roll when the Leg's servos are inactive while the green trend depicts the active case.

The bot rolls rightwards when the feedback and the input to the revolute joints are disabled. The maximum roll is 5.8 ° with some minute leftward tilts. However, when the feedback is enabled and appropriate signals to servos are calculated using the derived mathematical equations, the maximum roll is such case is -3.15 °. The active roll control trend is fluctuating which can be stabilized by using filters.

CONCLUSION

Based on the results discussed (Fig.10 and Fig. 11), we can infer that a legged-wheeled robot can achieve observably much better roll and pitch stability as compared to a rigid suspension. Such a legged-wheel robot that can dynamically balance its roll and pitch can be of immense help in the fields of material handling, defense, surveillance etc. It can also be implemented in automotive industry to improve passenger safety and comfort.

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