Hybird system of wheelled bipedal robot

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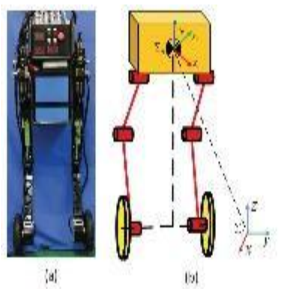
I. Problem formulation

The allignment of different objects in warehouses is an essential task for different factories. The space of limitation for storage of raw materials or even end products obliges the design of a warehouse to depend on storage of different objects in different levels. So the warehouse is not supposed to contain only flat ground. There could be stairs and different objects that a robot has to take into consideration to pass from. A wheeled robot is perfect to move on a flat surface due to it's speed. On the other hand, Climbing up stairs and irregular floor may require different technique in movement. This project proposes a robot that has the ability to interchange between both in order to assure robustness in daily operations.

II. Hybrid system identification



Figure[1]: Biped wheeled robot [1]

The biped wheelled robot has the ability to move with its wheels as well as performing a gait cycle of a human. Performing a gait cycle is necessary to climb stairs in a warehouse or passing over a small obstacle on the floor. The movement is performed using the wheels otherwise. So those are the main subsystems where the control algorithm interchanges between both.

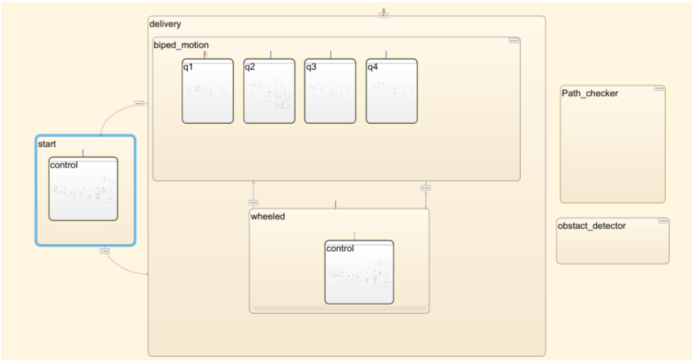


Figure [2]: State machine of the system.

III. Concurrent states

1) *Delivery:*

This state has the two different types of motion which are bipedal and wheeled, assuming that the desired point is not reached yet, the system keeps moving in this state.

2) *Obstacle detection:*

This state determines the presence of tough terrains which is the point of transformation between the two motion states.

3) *Path checker:*

This state determines wheter the path is achieved or not.

IV. Inputs and outputs

A camera is needed to determine the presence of tough terrains. The speed of the wheels are taken into the system with encoders as well as leg positions. The balancing of the upper mass is determined with IMU sensor.

On the other hand, The actuators of the wheels and the leg joints are the outputs of the system. The input to state flow is the desired points and height as well as the simulated sensors input.

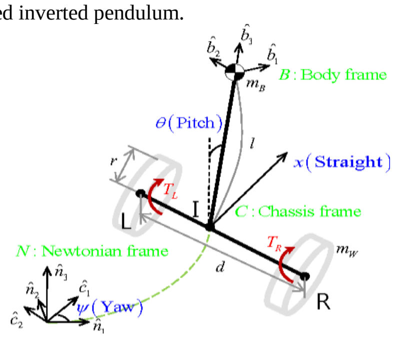
I. Modelling

The dynamic model in case of the bipedal motion is mainly based on position control of the joint angles which translates to be controlling the position of a dc motor. A dc motor has the following transfer function:

$$\frac{\theta(s)}{V(s)} = \frac{kt}{(Ra + s\, la)(Js^2 + Bs) + Kb\, Kt\, s}$$

So this function was discretized and entered into the model with zero order hold. The motor parameters were chosen similar to those of dc motors found in the market.

The wheeled motion is governed by the equations of the two wheeled inverted pendulum.



Figure[3]: two wheeled inverted pendulum.

As stated before, a two wheeled inverted pendulum has The following mathematical model :

$$(M + 2Mw + 2\frac{Iw}{r^2})\,\ddot{s} + ml\,\ddot{\theta}\cos(\theta) - ml\dot{\theta}^2\sin(\theta) = \frac{tL}{r} + \frac{tR}{r}$$

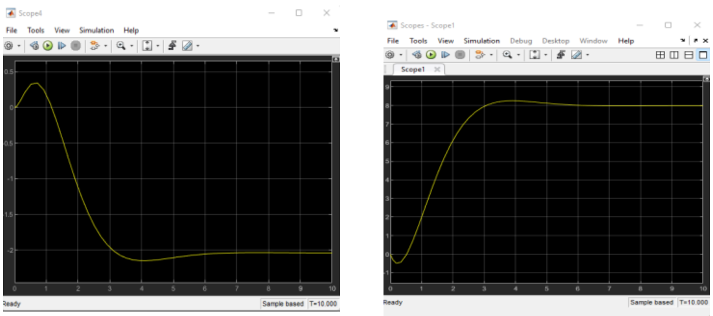
$$\left(Ip + 2\left(Mw + \frac{Iw}{r^2}\right)d^2\right)\ddot{\varphi} = 2d(\frac{tL}{r} - \frac{tR}{r})$$

$$ml\ddot{s}\cos(\theta) + (ml^2 + Im)\ddot{\theta} - mgl\sin(\theta) = 0$$

Those differential equations were taken into mathematica program and Linearized about the operating point of balancing the generate a five Degrees of freedom state space model which is fully controllable.
When generating the eigen values of A matrix symbolically, the presence Of positive eigen values assures that the system is unstable. The K matrix Was then equated after plugging in the numerical values of the symbols and The poles were needed to be shifted to the negative half to stabilize the system The state-space model is then taken and inserted to matlab function for the model.

VI: CONTROL RESULTS

The state feedback controller showed a nice performance when stabilizing the system. Figure[4] shows the response of S and phi states which were required to reach a certain Reference. The reference tracking was achieved with the adjustment of the feedforward Gain.

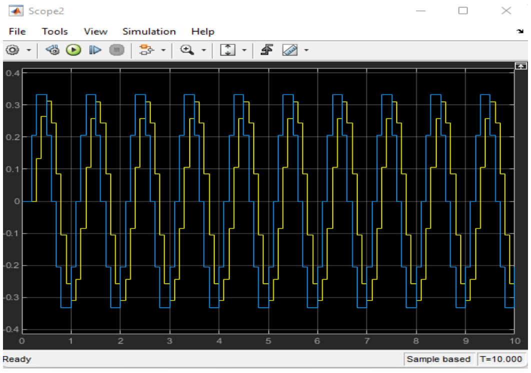


Rotation angle speed

Figure[4]: state feedback response

The other states were required to be zero as the tilt angle should be stabilized to achieve Balancing during wheeled motion.

On the other hand, the discretized PID controller behaved well with a small error during The biped motion, the angles of the motors were periodic so as to achieve the gait cycle Of a normal bipedal locomotion. Figure[5] shows the results of the reference tracking of One joint.



Figure[5]: signal tracking of first joint in biped motion.

References

1- Zemin Cui , Yaxian Xin , Shuyun Liu , Xuewen Rong and Yibin Li "Modeling and Control of a Wheeled Biped Robot" Micromachines 2022, 13, 743 (2022).