Motion Control for Gait Balancing of quadrupedal Robot

luis Arias, , *luis.aac29890@gmail.com,*

***Abstract*—Quadrupedal robot is defined as the four legged robot, which try to mimic the dog behaviour as well as its motions. Most of the reference about quadrupedal robot are focusing to dog-like robot. One of the challenges is to design a robust robot able to make motion planning by itself in a complex environment. Balancing Motion became an important topic, design a optimal control system to improve the gait performance. For this short article, I'm going to solve the problem the gait balancing through feedback control based on robot dynamics.**

***Index Terms*—ZOM, DOF, ZOP, Coriolis Matrix, Inverse Dynamic.**

I. Introduction

The quadrupedal is one kind of 4 legged robot similar to dog animal. One of the most sophisticated dog robot is BigDog of Boston Dynamics Company. This robot robot has a complex stability control system for locomotion, is able to make others actions, like: walking, running, jumping,climb stairs, etc. This robot has complex control system applied for each application. In addition to that, the perception, navigation, manipulation are some of the additional features that the quadrupedal robot has to have, making of BigDog robot awesome in me point of view. However, its is really heavy in comparison to other quadrupedal robot, because of the hydraulic system the go though it. This system made more powerful for a bunch of activities. The hydraulic system generated a noisy noise, this problem is being kept in all Boston dynamic Robots. In other hand the locomotion is a vital part of the control for quadrupedal robot. The complexity of the environment and the physics of the robot make the motion control complicated. Even Though the complex of motion, this is handled, and there are many approaches to solve this problem. Huai C Liu in 2010 Present a method for designing reliable gaits for structural symmetrical quadruped robot capable of performing statically stable, omnidirectional walking on irregular terrain where the control algorithm is proposed by applying virtual components at some strategic locations Johan I. present in his thesis "Quadruped robot control and variable leg transmissions based in six papers ranged from development tools to actuation of robot legs.

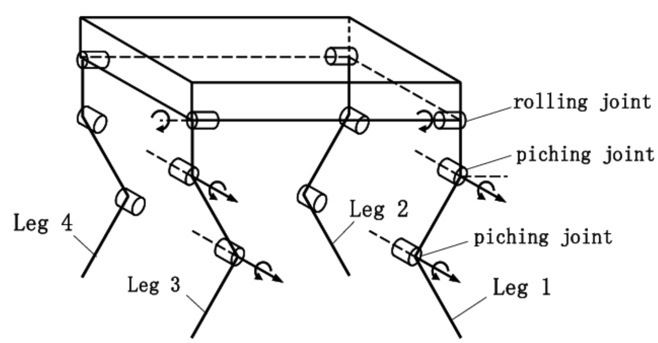
Shaml F. in 2019 presents experimental results using a passive whole-body control approach for quadruped robots that achieves dynamic locomotion while compliantly balancing the robot's trunk formulating the motion tracking as a Quadratic Program (QP) that takes into account the full robot rigid body dynamics, the actuation limits, the joint limits and the contact interaction.

Michelle F. shows a novel torque control for locomotion challenge and complex environments that are predominantly non-Flat In this context, control of contact forces is fundamental to ensure stable contacts and equilibrium of the robot.In this paper they propose a planning/control framework for quasi-static walking of quadrupedal robots, implemented for a demanding application in which regulation of ground reaction forces is crucial. Luther R. presents an attitude control strategy for a high-speed quadruped trot. The forces in the trot are redistributed among the legs to stabilize the pitch and roll of the system. An important aspect of the strategy is that the controller works to preserve the passive dynamics of quadruped trotting that are accurately predicted by the spring-loaded inverted pendulum (SLIP) model. Nie H. presents a motion planning algorithm of static walking gait for a quadruped robot. First, the kinematics and dynamics equations of quadruped are built which can be used to research legged locomotion. Based on kinematics equations, foot trajectory is proposed with some optimization methods.

For this article, the motion control of the 4 legged robot is solved using feedback control using the IMU sensor to feedback the input signal a minimize the error. Generated the motion planner with a acceptable gait control of the robot. The result will be showed in Gazebo environment.

A. Robot Model

The 4 legged robot that we will use, has 3 D.O.F for each limb. One in the hip, another one in the knee and the last one in the ankle. You can see the structure of the model in the following picture.

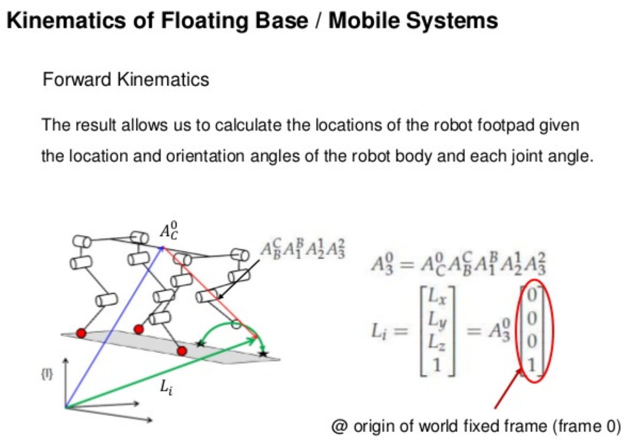


The stability in static stated can be easier to applied in simulated than bipedal robot, but make a robust stability control is the approach to solve in this article.

In the real robot to control the final position and orientation in the world frame of the robot joints is used homogeneous transformation, where the structure is given by:

$$\begin{bmatrix} r11 & r12 & r13 & p1 \\ r21 & r22 & r23 & p2 \\ r31 & r32 & r33 & p3 \\ 0 & 0 & 01 & \end{bmatrix} \tag{1}$$

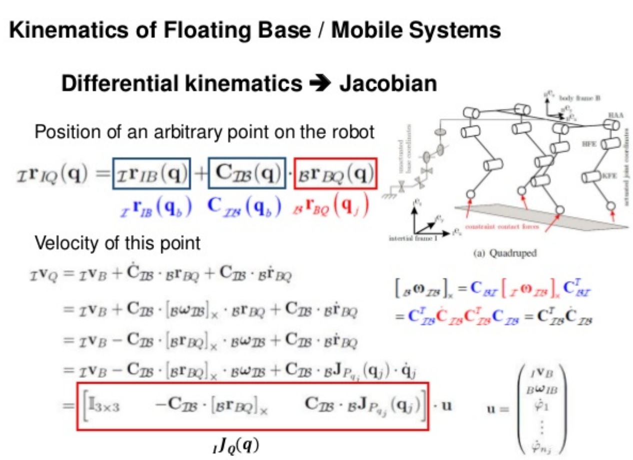
This is call the homogenous transformation. And the final configuration of the end effector is expressed as:



1) Forward Kinematic:

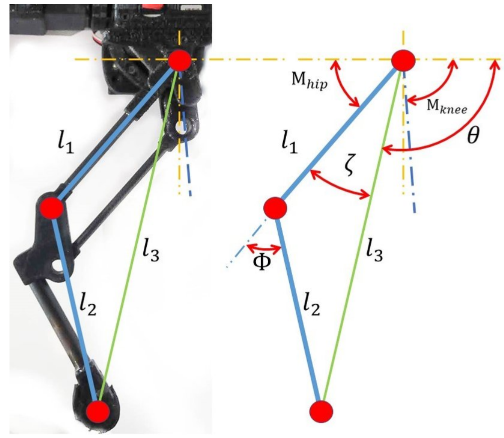
$$[X] = [H]\,[Xo]$$

Where H is the transformation matrix related to the base frame. Xo i the initial configuration of the end effector. One of the most easy manner to solve this, is using Davent-Halhenbert approach, but there are others like the Screw Theory, etc. This is a short concept of forward kinematic, but in real robot to control the robot, we have to use the velocity of the joints, so that means another concept of differential kinematics of velocity that will be described.



2) Inverse Kinematic: The inverse kinematic is used to get the angle of the joint. For open chain robot this problem is tricky, because there will be one, two and more solution. In order to solve it there are some approaches like: numerical, iterative calculation, etc.

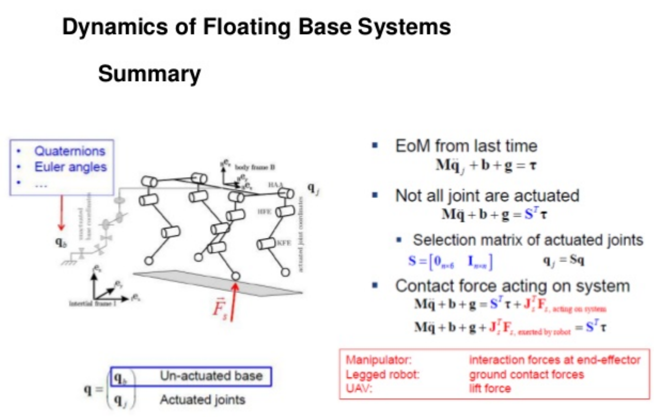
Geometrically, the inverse kinematics ca will solve like this figure:



Take in mind for robot than more than 3 D.O.F this approach is more difficult find the solution. Also is recommended now the configuration space of the robot to find solution appropiately and avoid singularities.

3) Inverse Dynamic: In kinematic is studied the motion a velocity of the robot, in dynamic will be studied the physics the motion, as dynamic of the rigid body based on the newton laws, this means. The lagragian equation and the newton second laws will be used.

Thi figure show, how can be repressed the dynamic equation in the 4 legged robot:



You'll realize the equation for quadrupedal robot is actually important to get a good walking controller.

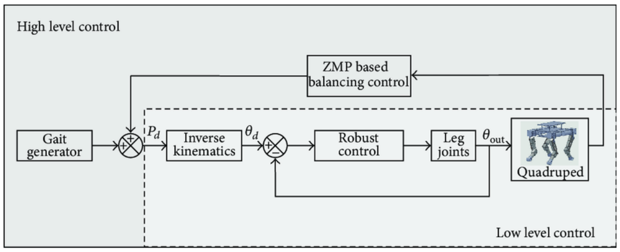
B. Control Theory

In control theory the feedback is used to improved the control system, making it more robust and optimal. There are many contro strategies to take into account when we want to design a control system. For Instance: Is the robot model is linear system, approaches like: PID controller, feed-forward+feedback control, state stated feedback, or based in the root's place. If we have no linear behaviour, the stability for non-linear system can be solve by: lyapunov function, backsteeping control, Hinf, predictive control, etc.

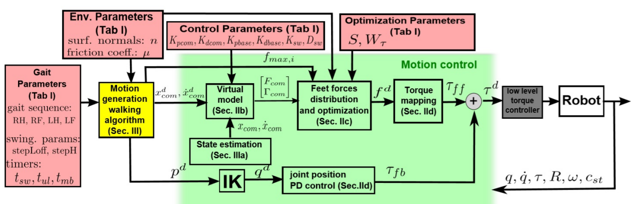
Nonetheless The PID control has been the ensured manner to solve motion control system for robots, this has demonstrated to have acceptable solutions.

For this topic we will enforce the control strategy to solve gait balancing of walking.

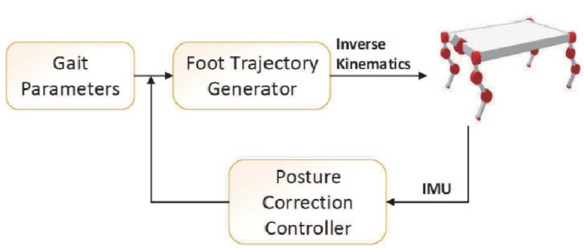
The walking an gait keep a relationship while the robot is moving, so to make a strategy control the block diagram can look like this:



Another example of the structure of motion control for this kind of robot is:



There are many strategies to solve complex application of quadrupedal robot, but for this article I'll be focusing in the full state feedback control:



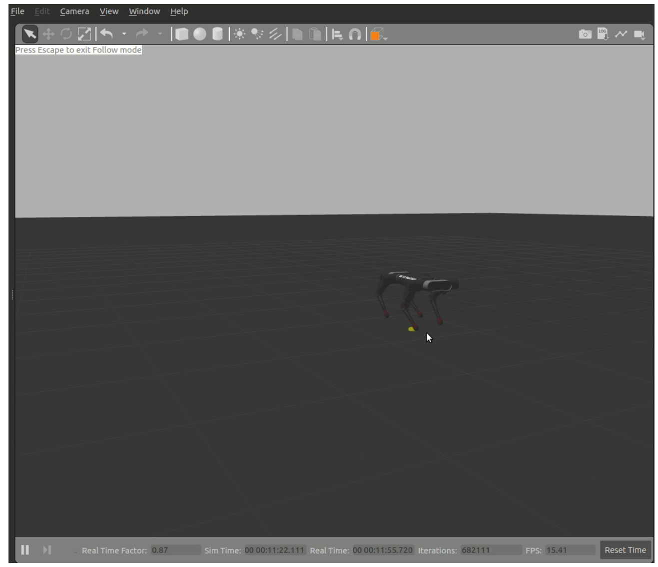
We could see these some examples have included the robot model. I mean: the forward an inverse kinematics.

Now, for walking control the trajectory generator make the displacement path of the frame for each leg. Finally the gait parameter make sure the balancing of the robot given by the control system performed.

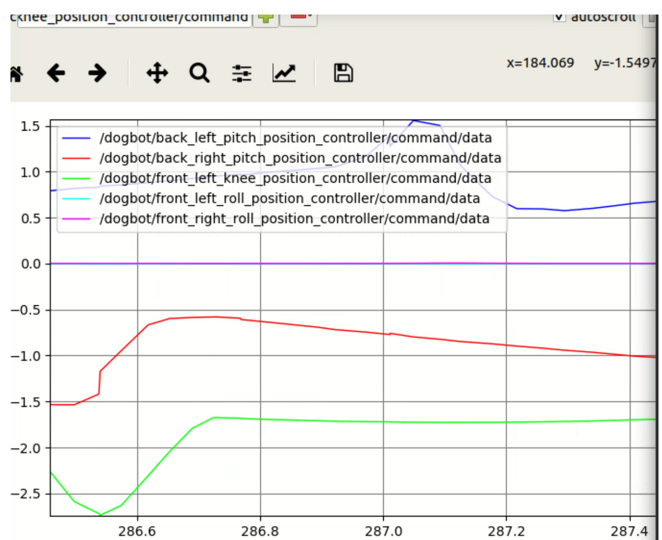
C. Result

To validated the importance of control system in gait and balancing of the walking behaviour. The proof was made using ROS as a communication system, and gazebo simulator as the quadrupedal robot. The quadrupedal robot based on the robot model mentioned before is simulated. This robot has a IMU sensor for feedback control. This means. The control system has to minimize la error, making the orientation keeping about zero. Even Though the use of force for control will make more accurated the system to be solve.

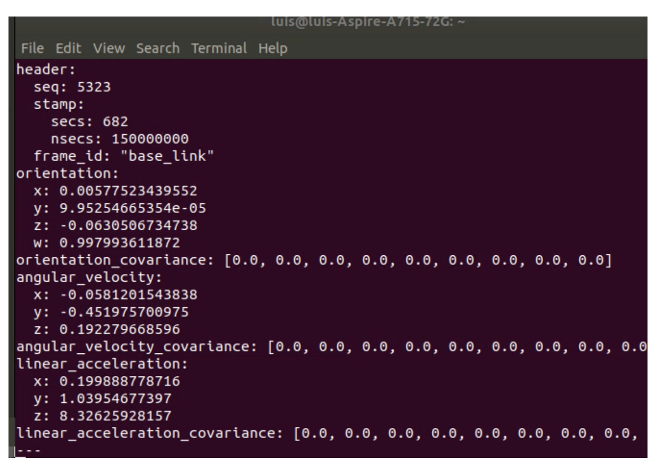
The simulation system will be strutured like this figure:



The robot is able to keep the stability even is applied external force to him.



In the next figure is showed the imu signal, we the gyroscope an accelometer are controlled to be stable.




```
header:
  seq: 5323
  stamp:
    secs: 682
    nsecs: 150000000
  frame_id: "base_link"
orientation:
  x: 0.00577523439552
  y: 9.95254665354e-05
  z: -0.0630506734738
  w: 0.997993611872
orientation_covariance: [0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
angular_velocity:
  x: -0.0581201543838
  y: -0.451975700975
  z: 0.192279668596
angular_velocity_covariance: [0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0
linear_acceleration:
  x: 0.199888778716
  y: 1.03954677397
  z: 8.32625928157
linear_acceleration_covariance: [0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
---
```

Finally, This result is a example how control the gait an balancing of a robot while he is walking.

II. Conclusion

The short article shows how can be design control system for gait an balancing of 4 legged robot. Using ROS libraries and gazebo environment was possible demonstrated the solution of the control system. Also was show some concept of robot algebra, that are pieces of requirement to make a engineering solution. ROS is was of the most powerful platform for robotics as YARP are big used for the robot community around the world.

Gazebo has a sophisticated engine for rendering and emulate physics, planning, etc.

For implementation the model of the actuator for joints relays on the application. This can be DC motor, servomotor, pneumatic or hydraulic system.

References

[1] H. Chuangfeng, Realible Gait planning for a Quadruped Walking Robot, 2010.
[2] J. Ingvast, Quadruped robot control and variable leg transmissions, Stockholm-Sweden , 2006.
[3] S. Fahmi, Passive Whole-body Control for Quadruped Robots: Experimental Validation over Challenging Terrain , Robotics and Automation Letters, 2019.
[4] M. Focchi, High-slope Terrain Locomotion for Torque-Controlled Quadruped Robots, HAL archives-outvertes, 2018.
[5] S. Fahmi, Force Redistribution in a Quadruped Running Trot,ICRA, 2012.
[6] N. Hua, Static Gait Control for Quadruped Robot , IEEE International Conference , 2019.
[7] C. Gehrin, Control of Dynamic Gaits for a Quadrupedal Robot ,Disney Research Zurich, Switzerland , 2014.
[8] J. Wang, Gait Planning and Stability Control of a Quadruped Robot ,Disney Research Zurich, Switzerland , 2014.
[9] J. Silvino, Simplified Modelling of Legs Dynamics on Quadruped Robots Force Control Approach, Brazil , 2007.
[10] J. Pratt, A Controller for the LittleDog Quadruped Walking on Rough Terrain, USA-Florida.