Note of Fast Runner

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1 System dynamics

At the end of touchdown, assuming impact force is σ.

$$I(\ddot{\theta}) = \sigma x_z \tag{1}$$

$$y = Cx + Du$$

2 Code implementation

2.1 Modeling and Parameters

Main idea: a virtual wheel (as the massless leg) with radius r_{wheel} penetrate the ground for a distance r_{pen} where a external force point pe is attached on it. A body (with mass m and inertia Iyy) is attached to the center of wheel. Using PD control to interpret contact force when p_e is under the ground.

06/07 First prototype (Not used now)

- Joint numbers: 2
- Joint types: Floating planer joint for virtual wheel and pin joint for the body link.
- Contact point type: External force point
- Virtual wheel rotation: set proper initial condition for virtual wheel (also need a large inertia to make it nearly constant).

Contact force: Assuming the ground height is 0,

$$F_z = kp(0 - pe_z) + kd(0 - ve_z) \tag{2}$$
$$\phi = atan2(pe_x, r_{wheel} - pe_z) \tag{3}$$
$$F_x = F_z tan(\phi) \tag{4}$$

where ve is the velocity vector of the contact point pe, kp and kd are the PD control parameters. F_x is calculated so that the vector of ground reaction force $[F_x, F_y, F_z]^T$ will point towards the virtual pivot (the center of the virtual wheel).

Assessments:

- Need to set a non-zero inertia of massless virtual wheel (for numerical stability), otherwise the simulation will diverge.
- The inertia of virtual wheel need to be a large one for constant rotational speed.
- Suggestions: remove the massless link, attach the external force point to the body and change its position in the controller every time step.

06/08 Round Runner

- Joint numbers: 1
- Joint types: Floating planer joint for the body link.
- Contact point type: External force point
- Virtual wheel rotation: Assigning the external force point location with respect to the joint in an open loop manner.
- Contact force: Assuming the ground height is 0,

$$F_z = kp(0 - pe_z) + kd(0 - ve_z) \tag{5}$$
$$\phi = atan2(pe_x, r_{wheel} - pe_z) \tag{6}$$
$$F_x = F_z tan(\phi) \tag{7}$$

  where ve is the velocity vector of the contact point pe, kp and kd are the PD control parameters. F_x is calculated so that the vector of ground reaction force $[F_x, F_y, F_z]^T$ will point towards the virtual pivot (the center of the virtual wheel).

Assessments:

- The ground reaction force looks better, while the energy is not balanced (after a while it will move towards the negative x direction)
- The inertia of virtual wheel need to be a large one for constant rotational speed.
- Suggestions: Use the ground contact point (instead of external force point) to see how it goes.

06/11 Round Runner(with Ground Contact Point)

- Joint numbers: 1
- Joint types: Floating planer joint for the body link.
- Contact point type: Ground contact point, linear contact model[1]
- Virtual wheel rotation: Assigning the external force point location with respect to the joint in an open loop manner.
- **Contact point number** Parameterized, currently set to 3-6 points.
- Contact force: using built-in functionalities, only assigning the kp, kd (PD parameters in the z direction), kp_x, and kd_x (PD parameters in the x/y directions).

Assessments:

- Was able to generate a stable walking. Contact point has sliding.
- Due to setting up stiffness and damping for x and z separately, the force is not always point towards the virtual pivot.

[1]Disable the hardening stiffness in z direction by setting groundStiffeningLength to Double.NEGATIVE_INFINITY

3 Info mightbe useful

3.1 Going through references

1. Compare different terrestiral locomotions: Some parameters of the walk are not speed- dependent. The swing duration is a constant time parameter [1].
2. Trunk plays an important role during walking (birds) [2].
3. Resonance drives are considered with adaptive control for robotics. The use of these drives allows increasing machine's quickness several times and decreasing energy expenses simultaneously 10-50 times [3].
4. Light weight leg (ostrich vs. moa) can run faster[5]. Also a famous allometric equation:

$$Y = M^{3/4} \tag{8}$$

   where M is the body mass, Y is the metabolic rate.

5. Human's walking may not be really self-optimized: the preferred speed maybe different from the energetically optimal speed[9].
6. It is concluded that the most important adjustment to the bodys spring system to accommodate higher stride frequencies is that leg spring becomes stiffer [17].
7. magic equations for imd force (ostrich) [24]
8. gait frequency was reported to be highly correlated with the resonant frequency of the mass-spring model [28]
9. WABIAN, why you are here? [29]

3.2 Categories

1. Nonlinear oscillators/components [3, 6, 8, 9, 11];
2. Bio-inspired robots: [7, 30]
3. Reference I should read: [10, 14, 25, 26]
4. Article not found (or not free)[4].
5. Robots in 3D: [12]
6. Stability analysis (Monocycle, linearized system) [13]
7. Biology/Anatomical structure [15, 18]
8. Light weight fast robot [16, 23]
9. take a look again [19]
10. mechanism design of robot [20]
11. quadruped reference [21]
12. human energy cost [22]
13. walking parameterization [27]

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