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[Dynamic Locomotion in the MIT Cheetah 3 Through Convex Model-Predictive Control]

Summary

This paper presents an implementation of model predictive control to determine ground reaction forces. Those forces are then used to compute the torques needed to control the robot Cheetah 3.

Some key points of this paper:

- MPC looks simple, at least from the perspective of model.
- 0.5 seconds of prediction horizon

Major Analysis and Comparison

1) the main optimization framework, the optimization variable x are body position, body velocity, body angle, body angular velocity12 variables. U are contact forces here, so 4*3(x,y,z) = 12, here in the paper, for simplicity, the gravity is augmented into state so we can see 13.

$$
\begin{aligned}
\min_{\mathbf{x},\mathbf{u}} \quad & \sum_{i=0}^{k-1} ||\mathbf{x}_{i+1} - \mathbf{x}_{i+1,\mathrm{ref}}||_{\mathbf{Q}_i} + ||\mathbf{u}_i||_{\mathbf{R}_i} && (18)\\
\text{subject to} \quad & \mathbf{x}_{i+1} = \mathbf{A}_i\mathbf{x}_i + \mathbf{B}_i\mathbf{u}_i, i = 0 \ldots k-1 && (19)\\
& \underline{\mathbf{c}}_i \le \mathbf{C}_i\mathbf{u}_i \le \overline{\mathbf{c}}_i, i = 0 \ldots k-1 && (20)\\
& \mathbf{D}_i\mathbf{u}_i = 0, i = 0 \ldots k-1 && (21)
\end{aligned}
$$

   - The reference trajectory is commanded by human operator. (0.5 ~ 0.3 seconds), the recalculation is (0.05 ~ 0.03s)
   - **fixed time gait,** so for sometime, the contact forces leg changes → matrix changes → different optimization problem. A detect scheme is used, whenever the foot is detected on the ground, immediately switch into contact mode for that leg.
   - The matrix A and B here have some approximation to linearise it and make it convex.

2) The whole framework seems to be similar to TOWR:
   - in the sense of both using an operator input;

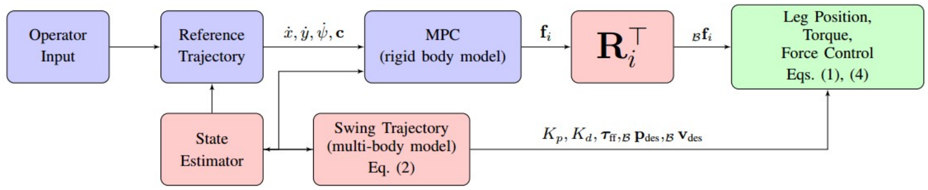

Fig. 2. Control system block diagram. The reference trajectory contains desired velocities and contact sequence from the operator. Blocks shaded blue run at 30 Hz, blocks shaded red run at 1 kHz, and blocks shaded green run at 4.5 kHz.

- reference trajectory is computed based on the state estimation again, so assume the reference trajectory can be computed online here (no need to offline actually, in ocs2, there are already some default gaits and can be used directly without towr)
- One advantage of towr is might that it could **theoretically handle really tough** terrains (unlike here normally we do some easy ones), and in towr, the horizon of trajectory is therefore predefined, (because computing trajectory is time-consuming) so no feedback from estimation goes to reference generation.

3) It can blindly fly trotting and go over a stair. Interesting
4) it can handle very tough lateral kick from a person. (estimation and feedback matters here, and prediction matters.)

Thoughts

1) For MPC, it seems people tend to compute contact forces, for different legs (either in contact with ground or in the air, they have different constraints)
2) need to look at the different mpc approaches. Here the model is simplified and convexized to make solver work. Orientation maybe could be more sophisticated.