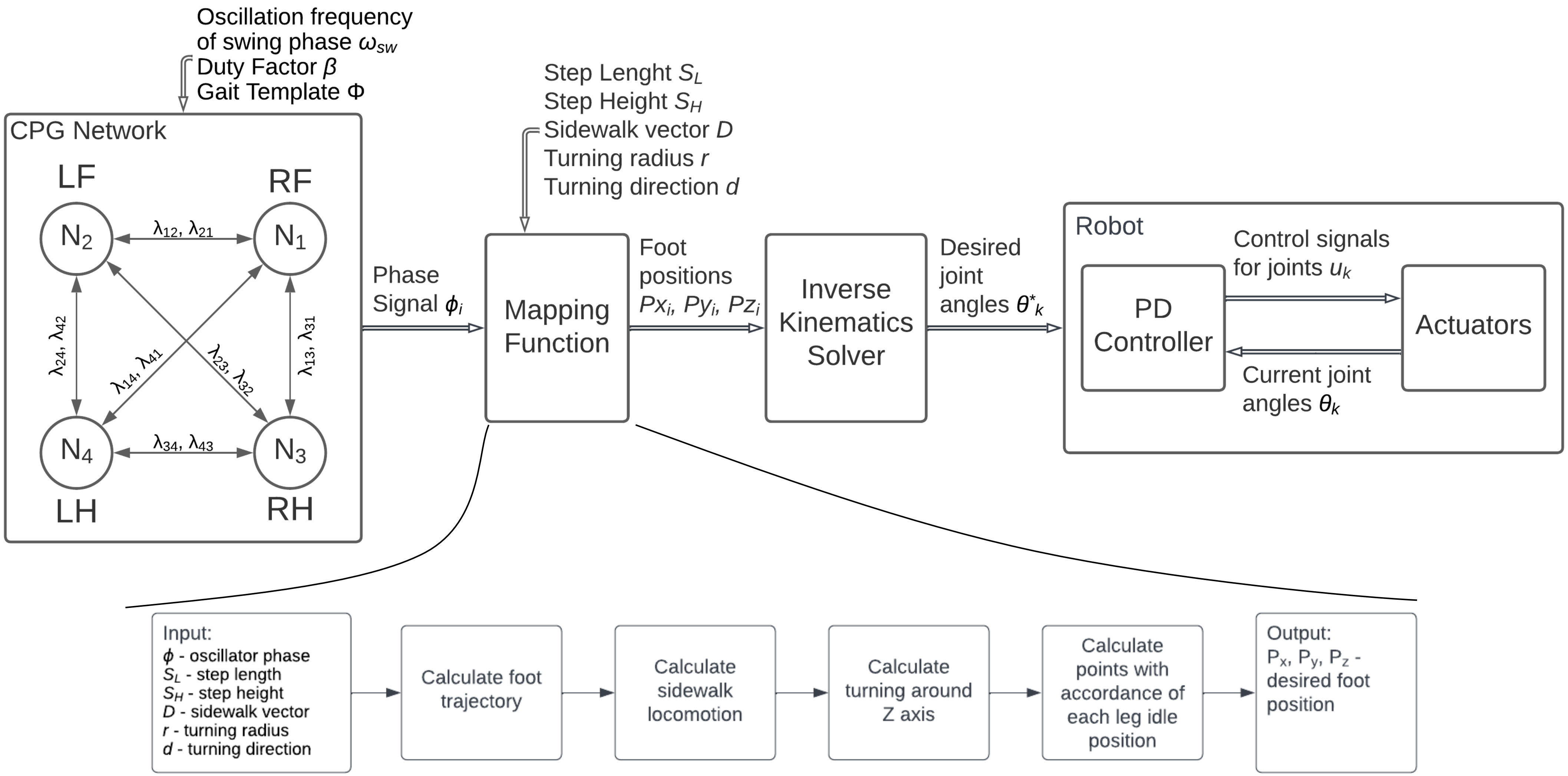
Control of Simplified Walking Robot Model using PMTG architecture

Vladimir Danilov

Block diagram of CPG-based Gait Generator

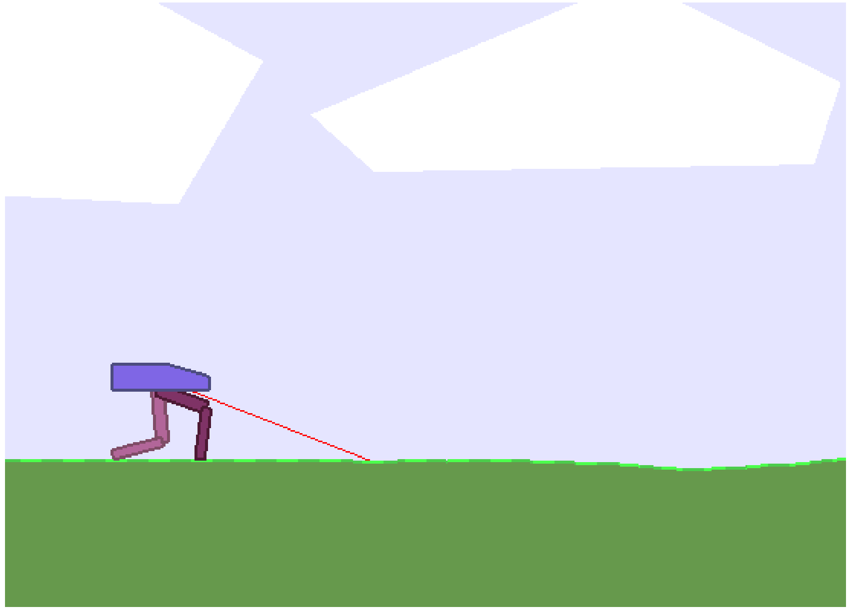


Experimental Hardware Results

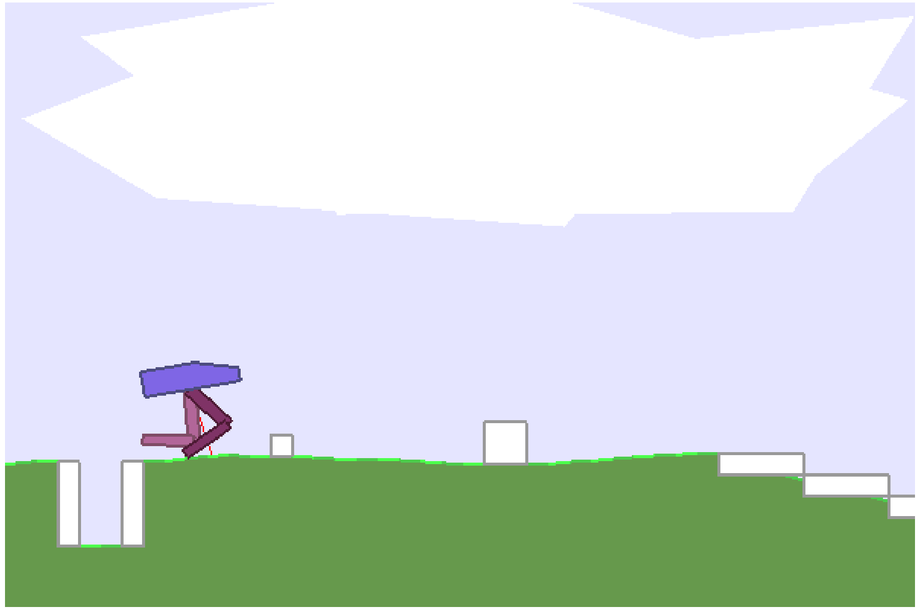
[Watch on Youtube]

Simplified Walking Robot Model

Bipedal Walker

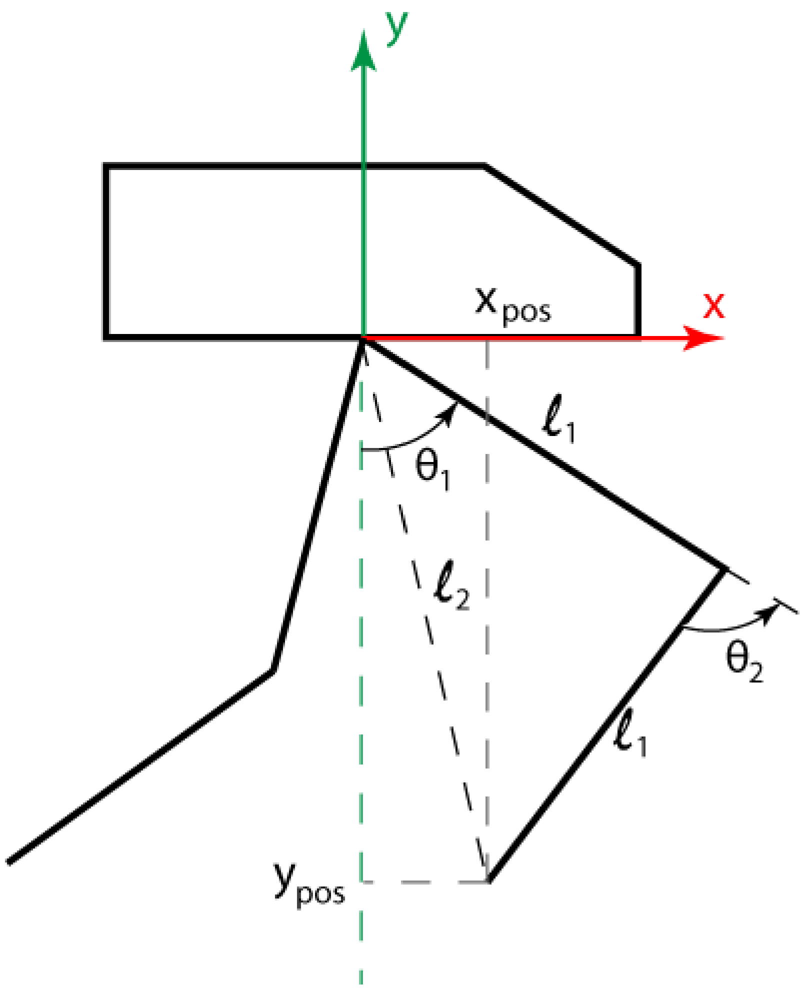


Bipedal Walker Hardcore



Starting State: Random position upright and mostly straight legs
Episode Termination: when the robot body touches ground or the robot reaches far right side of the environment
Solved Requirements: to get average reward greater than 300

Kinematics



Forward Kinematics:

$$l_2 = 2l_1^2(1 + \sin\theta_2)$$

$$x_{pos} = l_2 \sin\left(\theta_1 + \frac{\theta_2}{2}\right)$$

$$y_{pos} = \sqrt{l_2^2 - x_{pos}^2}$$

Inverse Kinematics:

$$l_2 = \sqrt{x_{pos}^2 + y_{pos}^2}$$

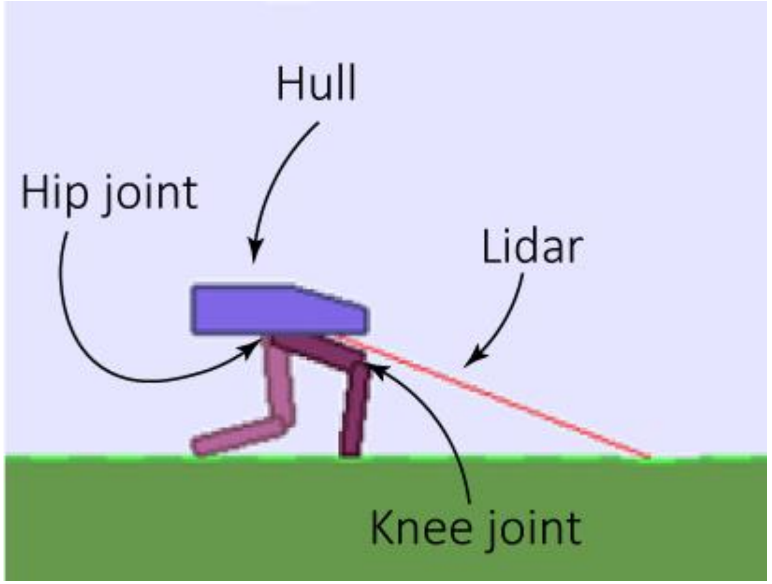
$$\theta_1 = \mathrm{atan}\frac{x_{pos}}{y_{pos}} + \mathrm{acos}\frac{l_2}{2l_1}$$

$$\theta_2 = -2\,\mathrm{acos}\frac{l_2}{2l_1}$$

Environment

Num	Observation	Min	Max
0	hull_angle	0	2π
1	hull_angularVelocity	-∞	+∞
2	vel_x	-1	+1
3	vel_y	-1	+1
4	hip_joint_1_angle	-∞	+∞
5	hip_joint_1_speed	-∞	+∞
6	knee_joint_1_angle	-∞	+∞
7	knee_joint_1_speed	-∞	+∞
8	leg_1_ground_contact_flag	0	1
9	hip_joint_2_angle	-∞	+∞
10	hip_joint_2_speed	-∞	+∞
11	knee_joint_2_angle	-∞	+∞
12	knee_joint_2_speed	-∞	+∞
13	leg_2_ground_contact_flag	0	1
14-23	10 lidar readings	-∞	+∞

Num	Action	Min	Max
0	Hip_1 (Torque / Velocity)	-1	+1
1	Knee_1 (Torque / Velocity)	-1	+1
2	Hip_2 (Torque / Velocity)	-1	+1
3	Knee_2 (Torque / Velocity)	-1	+1



Reward function:

$$r_{fw} = \frac{13}{3}\left(p_x(t) - p_x(t-1)\right) - moving\ forward\ reward$$

$$r_{hull} = -5(|\vartheta(t)| - |\vartheta(t-1)|) - hull\ deviation\ penalty$$

$$r_\tau = -0{,}028\sum_{i=1}^{12}|a_i| - torque\ penalty$$

$$r_{es} = \begin{cases} -100, & if\ p_x < 0\ \ or\ hull\ touches\ ground \\ 0, & otherwise \end{cases} - early\ stopping\ penalty$$

$$R = r_{fw} + r_{hull} + r_\tau + r_{es} - total\ reward,$$

$where:$

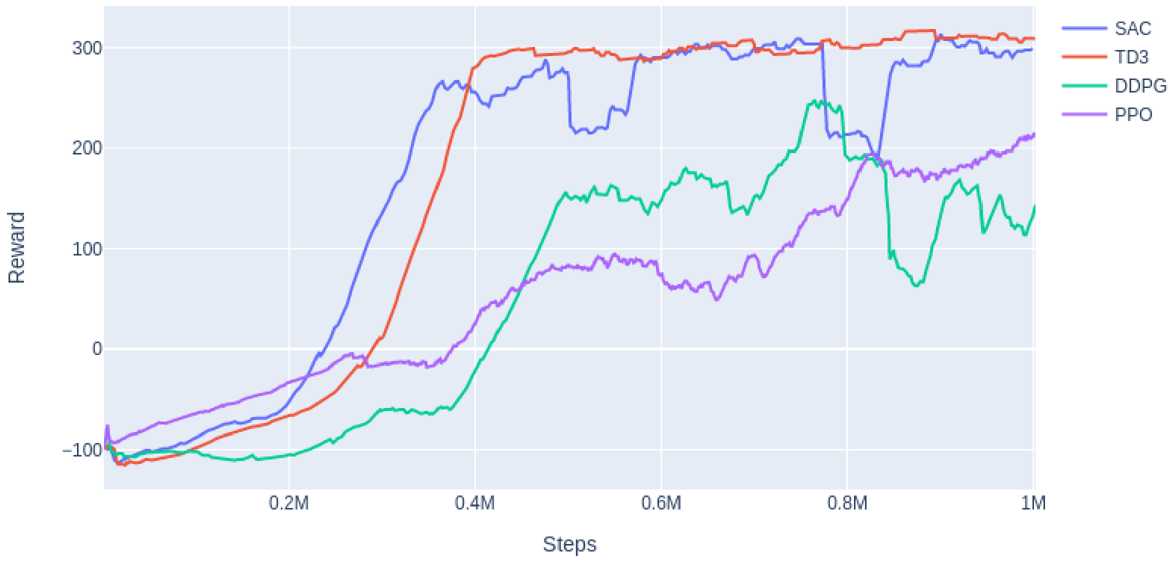
$p_x - x\ position,$

$\vartheta - hull\ angle$

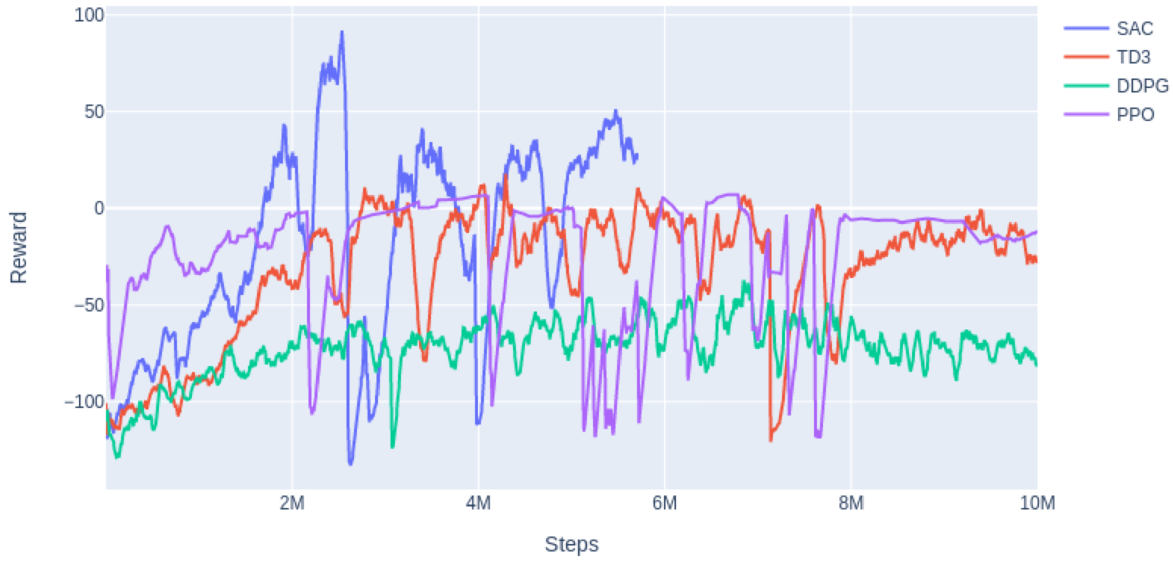
$a_i - applied\ action$

Learning with Vanilla RL Algorithms

Bipedal Walker

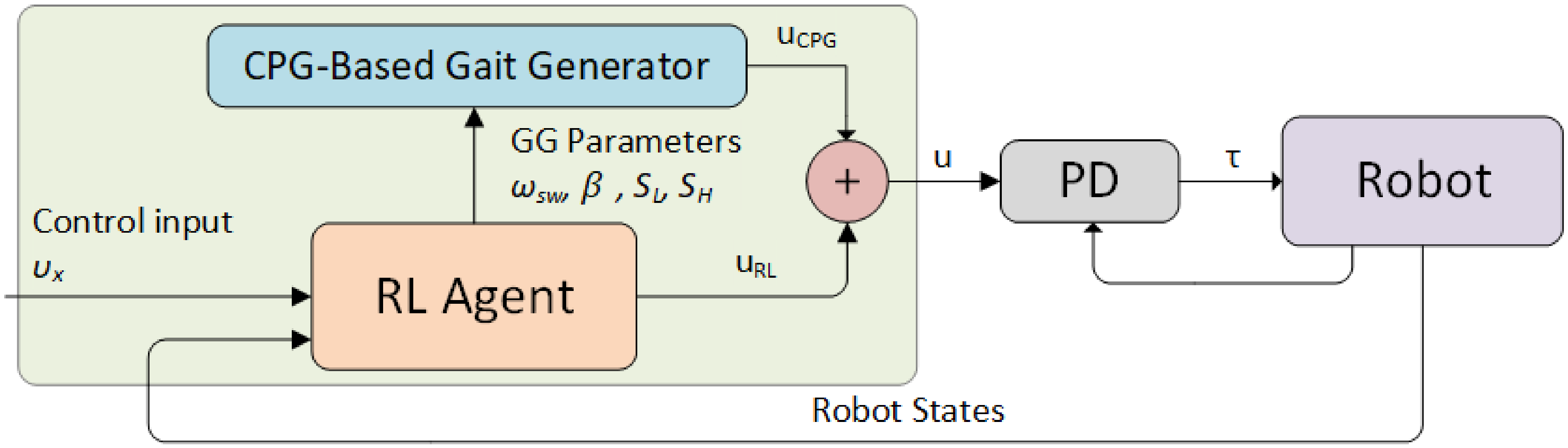


Bipedal Walker Hardcore



*all the hyperparameters were optimized by Tree-structured Parzen Estimator algorithm

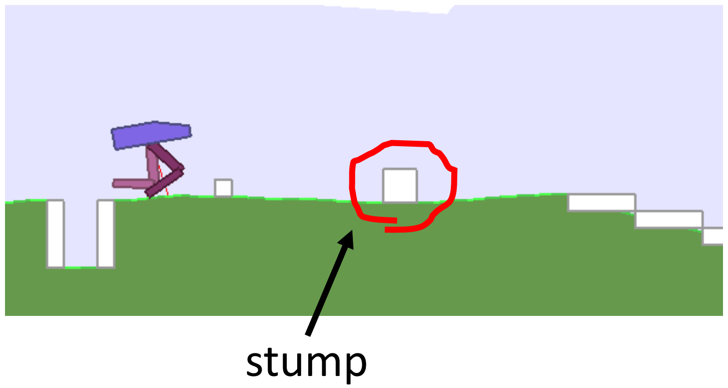
Policy Modulating Trajectory Generator (PMTG) Architecture



Supposed agents: TD3, SAC

Tricks to enhance performance:

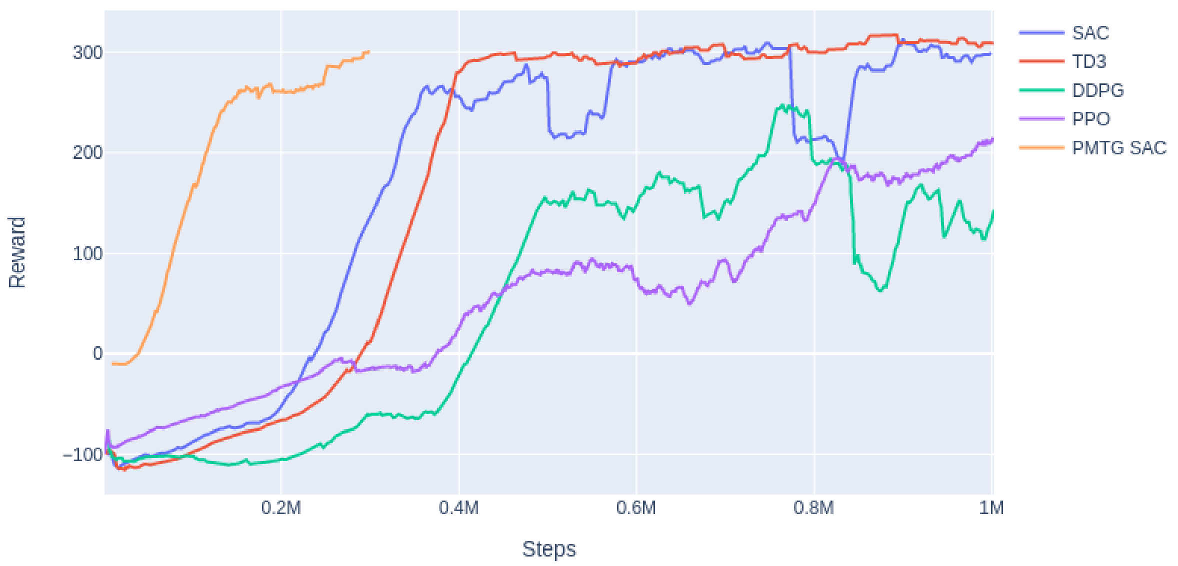
- During training the actions are repeated for three steps.
- When the agent falls, the terminal reward is clipped to zero.
- The reward is scaled by 5.
- Noises are added to the actions.
- When training, the probability of encountering a stump is increased.



Learning with PMTG

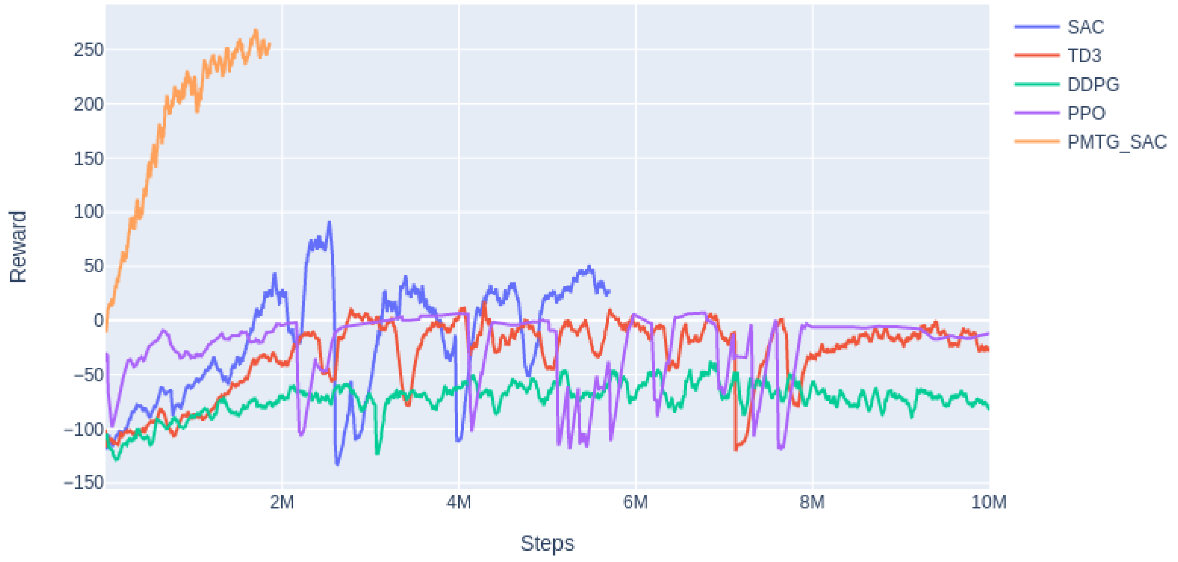
Подумать, как наглядно обозначить то, что в итог

Bipedal Walker



Learned agent 100-episode average score: 304.24
Episodes before solve: 696

Bipedal Walker Hardcore



Learned agent 100-episode average score: 302.92
Episodes before solve: 7280

OpenAi Leaderboard

Bipedal Walker

User	Episodes before solve	Write-up	Video
Nandino Cakar	474	writeup	
ZhiqingXiao	0 (use close-form preset policy)	writeup	
Nick Kaparinos	800	Write-up	gif
shnippi	925	writeup	

My learned agent 100-episode average score: 304.24
Episodes before solve: 696

Bipedal Walker Hardcore

User	Episodes before solve	100-Episode Average Score	Write-up	Video
Nick Kaparinos	15500	305.40 ± 21.35	Write-up	gif
Alister Maguire	N/A	313	Write-up	gif

My learned agent 100-episode average score: 302.92
Episodes before solve: 7280

Learned Agent Video

Bipedal Walker

Watch on Youtube

Bipedal Walker Hardcore

Watch on Youtube

Bipedal Walker Hardcore with Velocity Control

Reward function:

$$r_{fw} = \frac{4}{30}\exp\left(\frac{(v^* - v)^2}{0.2}\right) - moving\ forward\ reward$$

$$r_{hull} = -5(|\vartheta(t)| - |\vartheta(t-1)|) - hull\ deviation\ penalty$$

$$r_\tau = -0{,}056\sum_{i=1}^{12}|\tau_i| - torque\ penalty$$

$$R = r_{fw} + r_{hull} + r_\tau - total\ reward,$$

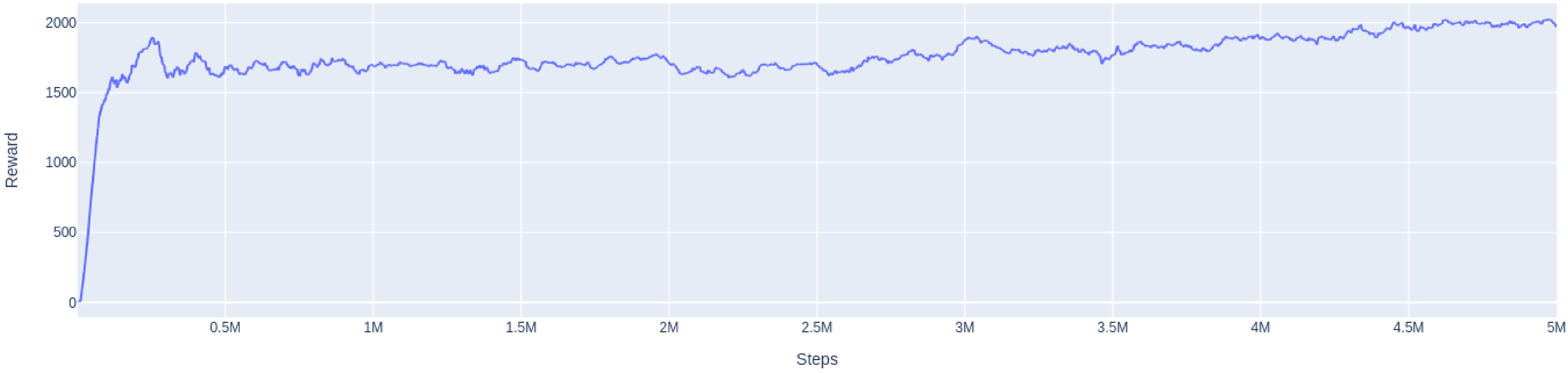
where:
p_x – *x position*,
ϑ – *hull angle*
a_i – *applied action*

Desired velocity:

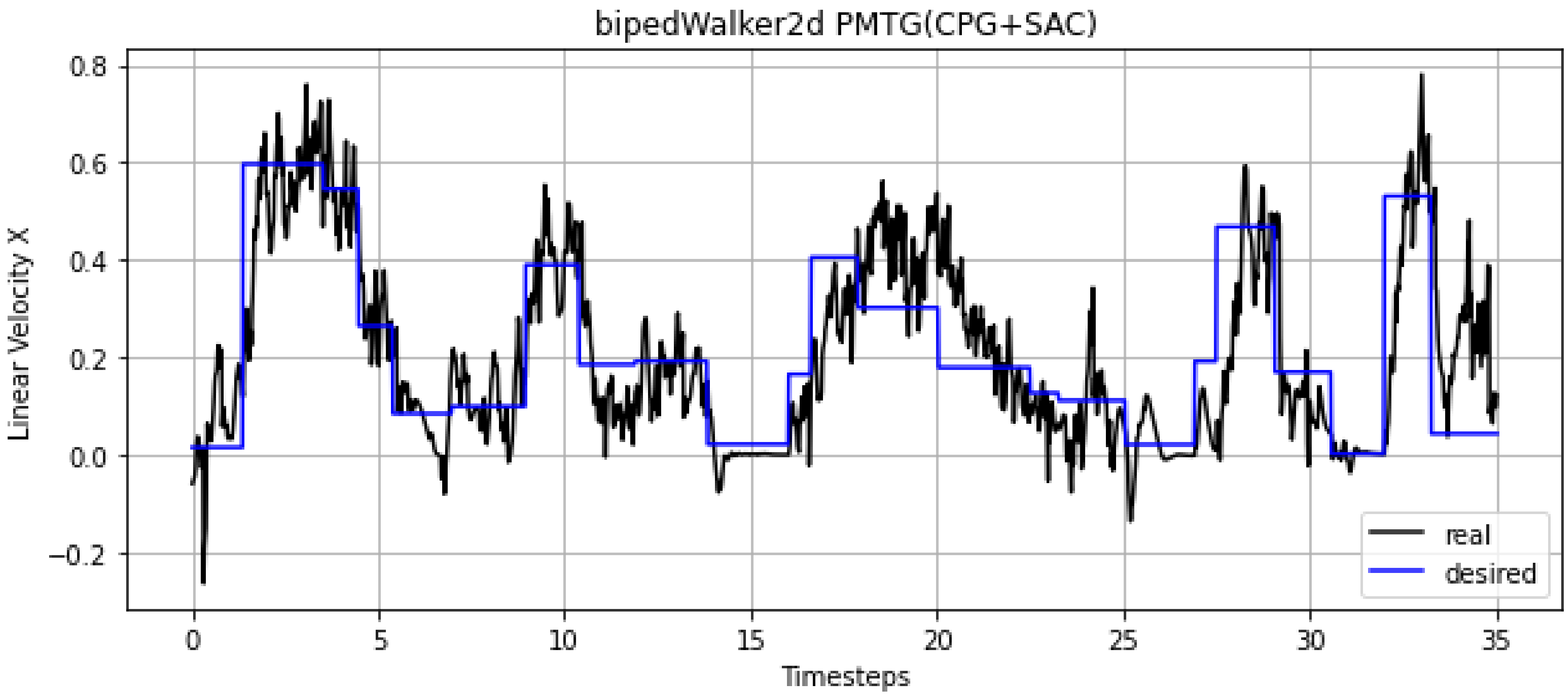
$$v^* \sim U[0, 0.6] - desired\ velocity\ distribution$$

$$t_{sw} \sim U[1, 5] - time\ before\ changing\ desired\ velocity$$

Learning Curve



Learned Agent with Velocity Control



Learned Agent with Velocity Control Video

Watch on Youtube

Thanks for Your Attention!

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