Towards Hybrid Active and Passive Compliant Mechanisms in Legged Robots

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Research question

Animals suffer from considerable sensorimotor delay as their robotic counterpart have a low delay in sensing and actuation. Animals still can perform highly agile tasks like parkour in the presence of substantial sensorimotor delay. However, robots with low delay cannot outperform animals yet. We believe that compliant in animals gives them the ability to compensate for the large sensing and actuation delay.

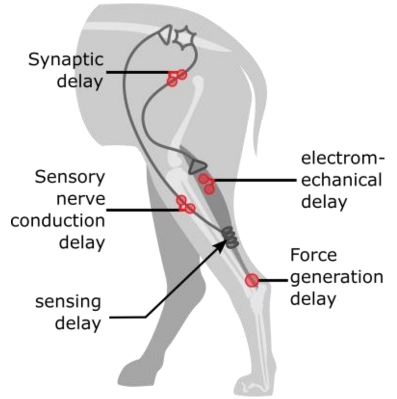

Figure 1. Observation of system delay in nature (modified from [1])

Figure 2. Agile, versatile animal locomotion/parkour

Figure 3. Robotic system with less than 1ms delay

Drop test experiment single leg

To investigate the effect of hybrid passive and active joint stiffness in the presence of communication delay we designed five experiments for a vertically dropped 2-DoF robot leg. It is released from a fixed height onto solid ground, and should rapidly converge to its standing height.

	Total(sum) Compliance [N/m]	Active Compliance [N/m]	Passive Compliance [N/m]	Control frequency [Hz]	Delay [ms]
Case 1	3120	0	3120	1000	0
Case 2	3120	3120	0	1000	0
Case 3	3120	3120	0	1000	37
Case 4	3120	1610	1510	1000	0
Case 5	3120	1610	1510	1000	37

Table 1. Experimental case scenarios

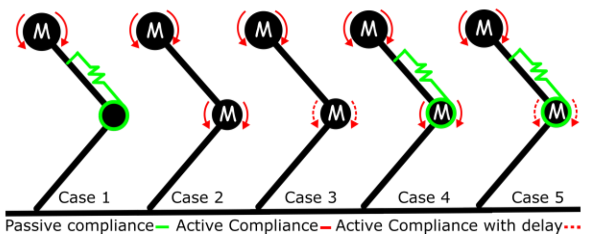

Figure 4. Different leg design[2-4]

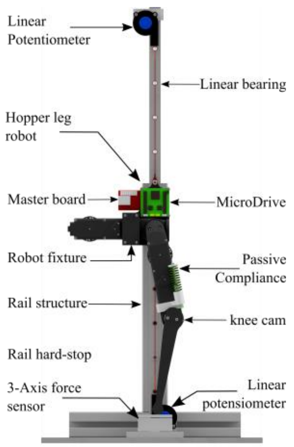

Figure 5. Experimental setup

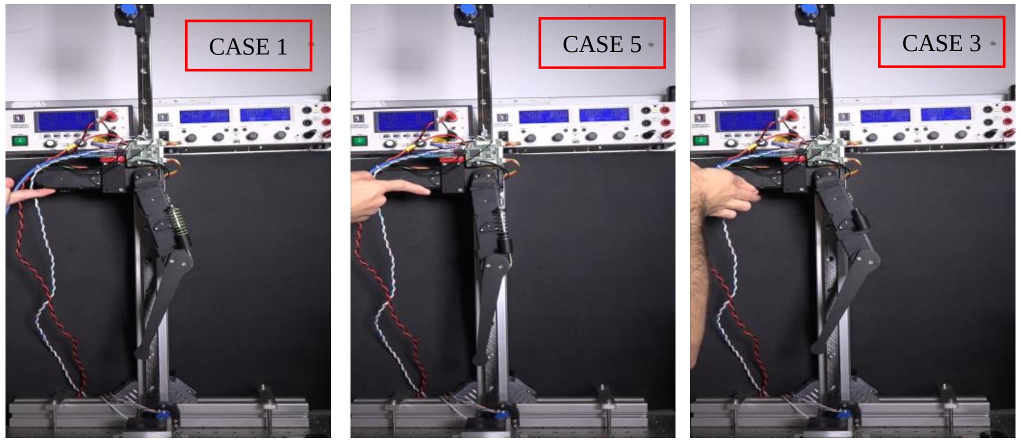

Figure 6. Result videos

Results and future direction

Results of drop test shows that the leg with active compliance of 52% in the presence of 37 ms delay still is able to land smoothly. However in the full active compliance, the landing controller fails in the presence of 37 ms delay and oscillates continuously. We believe passive parallel compliant is one of the key to find the source of the different motional behavior of animal and robots in table 2 summary of different leg design strategy presented.

Active Compliance	Pros	Control Authority
	Cons	Unstable to delay, high power consumption
Passive Compliance	Pros	Energy efficient, robust in presence of delay
	Cons	Without control authority
Passive + Active Compliance	Pros	Control Authority, robust to delay, energy efficient
	cons	Antagonistic behavior of motor and spring

Table 2. comparison of different type of compliant

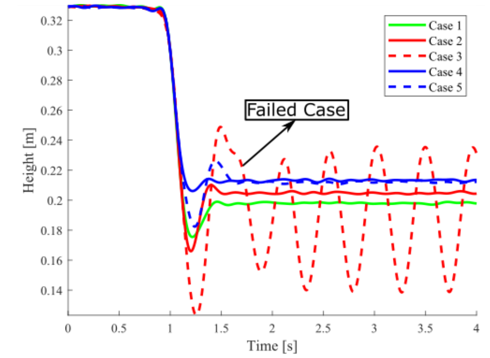

Figure 7. Simulation case scenarios

Simulation of quadruped landing with passive and active compliant

The following simulation shows how the last quadruped robot is still able to land successfully with the 27 ms commanding delay and 100Hz control loop frequency. The case 7, in comparison to other cases, shows that passive plus active compliant is robust to sensorimotor delay, is more energy efficient and yet has the control authority by online modifying active compliant part

	Total(sum) Compliance [N/m]	Active Compliance [N/m]	Passive Compliance [N/m]	Control frequency [Hz]	Delay [ms]
Case 1	4680	0	4680	1000	0
Case 2	4680	0	4680	1000	0
Case 3	4680	4680	0	1000	0
Case 4	4680	4680	0	1000	17
Case 5	7020	2340	4680	1000	27
Case 6	7020	2340	4680	100	27
Case 7	7959	3276	4680	100	27

Table 3. Simulation case scenarios

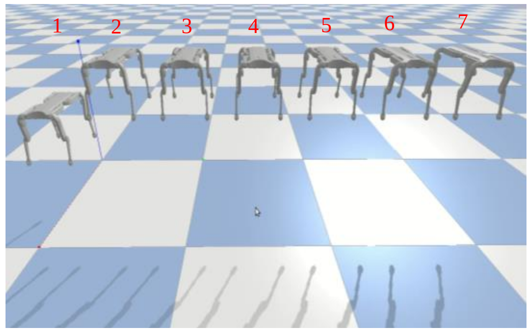

Figure 8. Simulation case scenarios

We are currently doing extensive simulations and experiments on the single leg and complete quadruped to characterize the landing behavior of robot in the presence of delay and low control frequency.
We plan to transfer our insights to a quadrupedal platform, to implement a hybrid compliant control.
We expect to observe a lower power consumption robot locomotion with the high fidelity of fully actuated robots.

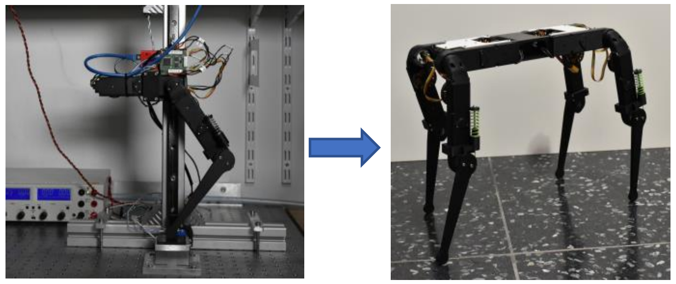

Figure 9. transfer single leg experiment to quadrupedal platform for test effect of compliant

References

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