# Explosive motion enhancement for series elastic actuated robots

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***Abstract*— Huge gearboxes limit the maximum joint velocities in series elastic actuated (SEA) robots. Although field-weakening (FW) can boost the output velocity significantly, it depletes the maximum useful current. Parallel elastic actuators (PEA) can not only enable power transfer between joints but also supplement torque reserves and enhance explosive motions. Initial jumping experiments with PEA and FW on a 3-degree of freedom (DoF) SEA robot has led to promising results.**

## I. Introduction

Agile locomotory motions often involve high joint velocities. But huge gearboxes in SEAs trade-off velocity for torque density. Further, back-EMF scales with velocities thereby reducing the useful voltage reserves.

Mammalian ballistic motions are accomplished by muscles and tendons that store and release energy, showcase variable impedance (VI) behaviour and transfer power between joints. In robots, while SEAs with VI mechanisms can exhibit the first two characteristics, power transfer between joints can be brought about only by articulated parallel elements [1].

The aforementioned problems can be addressed by i) embedding a bi-articulated PEA that enables power transfer from knee to ankle and ii) employing FW control [2] to reduce voltage requirements and attain higher velocities and hence better jumping performance.

## II. Methods

### A. Experimental hardware

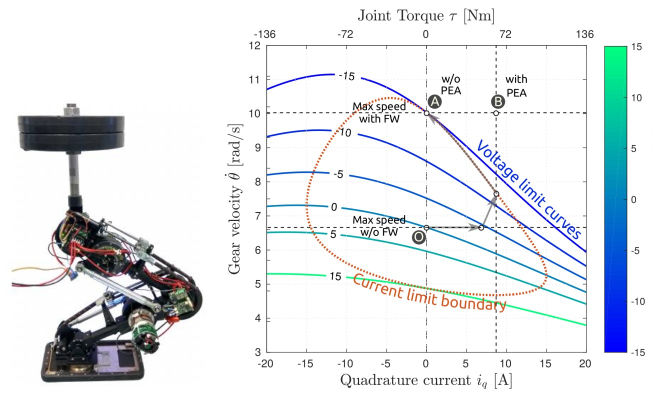
The eLeg is a 27kg, 3-DoF anthropomorphic legged robot, see fig. 1a. It can either be purely SEA-driven or be augmented with PEAs in distinct articulation configurations [3].

### B. Field weakening

FW by drawing upon the electrical motor dynamics reduces the voltage requirements for a given speed thereby boosting the maximum motor speed. However, FW reduces the available useful current reserves and hence the maximum output torque, see fig. 1b.

### C. Articulated parallel elastic actuation

While jumping when the link segments are almost fully extended just before take-off, the angular momentum from rotary joint motions cannot be effectively converted into whole-body translational momentum without parallel elastic elements, thereby limiting the jump height [1]. To address the issue as well as augment torque supplies, we employ biarticulated ankle-knee PEA along with a monoarticulated knee PEA. Further, the biarticulated PEA brings about power transfer from knee to ankle during explosive motions.




(a) (b)

Fig. 1: (a) The SEA-driven eLeg when augmented with PEAs. (b) Gray arrows show the action of the FW controller that boosts $\dot{\theta}$ within the current and voltage constraints (point A) for the motor used in this work on the $i_q$ - $\dot{\theta}$ plane in a frictionless setting. The joint torque axis corresponding to $i_q$ is shown above. Additionally, PEA favourably offsets the depleted maximum SEA torque during FW (point B).

## III. Jumping experiments

While jumping without PEAs, the vertical displacements of the heel and the robot CoM are 20 cm and 40 cm respectively. For jumps with PEAs, we tuned their pretensions to be held constant such that they provide for RMS of the joint torques at the start of the jump. With such a setting, the robot jumps 10% higher with 48% lesser energy consumption. The jump improvement can be attributed to energy transfer from the knee through the biarticulated PEA which aids in ankle lift-off. Simulations with FW without PEAs have demonstrated 14% improvement in the jump height as compared when without FW. PEAs along with FW would only further improve the jumping performance. Experiments to verify FW efficacy are currently underway.

## References

[1] J. Babic and J. Lenarcic, “Vertical Jump: Biomechanical Analysis and Simulation Study,” in *Humanoid Robots: New Developments*. I-Tech Education and Publishing, June 2007.

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