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Dynamic leg function of the BioBiped humanoid robot

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Abstract: This contribution presents the concept and design of the first robot of the BioBiped series, aiming to transfer biomechanical insights regarding the mechanics and control of human walking and running to bipedal robot design and actuation. These are supported by preliminary experiments with the robot, where synchronous and alternate hopping motions could be successfully realized. This demonstrates that the robot design has the potential to develop dynamic gait patterns such as walking and running.

Keywords: Humanoid robot, bipedal walking and running, compliant segmented legs.

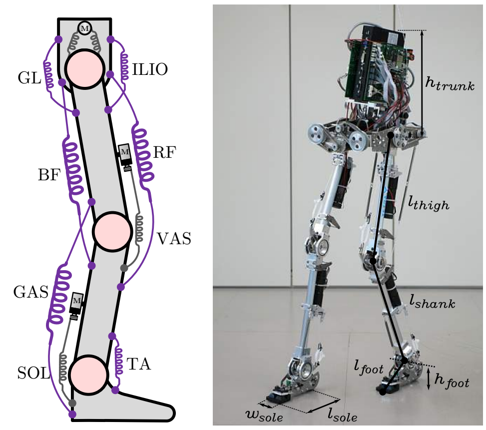
1. INTRODUCTION

Hopping, walking and running appear as natural and quite easy tasks for a healthy adult, yet for todays robots they impose big challenges. There are various problems for robots to perform these kinds of motion, including but not limited to mechanical robustness due to high joint torques, constraint forces and shocks from impacts, a high peak power demand especially in hopping and running, and, of course, postural stability of the robot.

Biomechanists have tried to point out mechanisms how these problems might be solved in human and animal locomotion [1-6]. We follow this approach by developing the lower body of the humanoid robot BioBiped1, the first prototype of a robot series aiming to transfer biomechanical insights regarding the mechanics and control of human locomotion to a novel bipedal robot design. With such platform, we hope to achieve human-like locomotion with various gaits (hopping, running and walking) with a single robot design. We aim at first to realize bouncing gaits like hopping and running, a central locomotor capability missing in most state-of-the art humanoid robots but surprisingly well described by simple template models [2]. This contribution describes the robot design philosophy and presents the results of preliminary experiments towards that goal.

2. ROBOT DESIGN CONCEPTS

The BioBiped1 robot (shown in Fig.1-right) is designed and realized in a way that allows to mimic important properties of the human locomotor system. One of them is segmentation: the robot leg is composed of three rotational joints in the sagittal plane (hip, knee and ankle) with segments sized according to human morphology. Another characteristic of the robot is the use of compliance at the joint level, which distinguishes it from conventional humanoid robots. This is achieved by series elastic, mono- and biarticular actuation of joints (represented in Fig.1-left) representing the main human muscle groups. Following biomechanical knowledge that power generation is mainly achieved by monoarticular muscles, while biarticular muscles mostly contribute to transfer this power between joints [6], monoarticular muscles (VAS and SOL) are active (i.e. with a motor in series to a spring, mimicking the muscle-tendon complex of extensor muscles) while the antagonist and biarticular structures are passive.



Dimensions and mass					
h_{trunk}	269	mm	l_{thigh}	330	mm
l_{shank}	330	mm	l_{foot}	122	mm
h_{foot}	67	mm	l_{sole}	168	mm
w_{sole}	40	mm	total mass	9.2	kg

Fig. 1 Biobiped1 robot. (Left) actuation concept: the monoarticular anti-gravity muscles Vastus (VAS) and Soleus (SOL) are active. The other muscles (biarticular: Rectus Femoris (RF), Biceps Femoris (BF), Gastrocnemius (GAS); monoarticular: Gluteus Maximus (GL), Iliopsoas (ILIO), Tibialis Anterior (TA)) are passive. The hip joint is actuated by extended series elastic actuators. (Right) Picture of the prototype and main dimensions (Down).

3. RESULTS AND DISCUSSION

As preliminary steps towards the realization of running, vertical hopping motions with synchronous or alternate motion of the legs (resp. synchronous hopping (Fig.2) and alternate hopping) were considered. The knee and ankle motors were controlled to follow reference po-

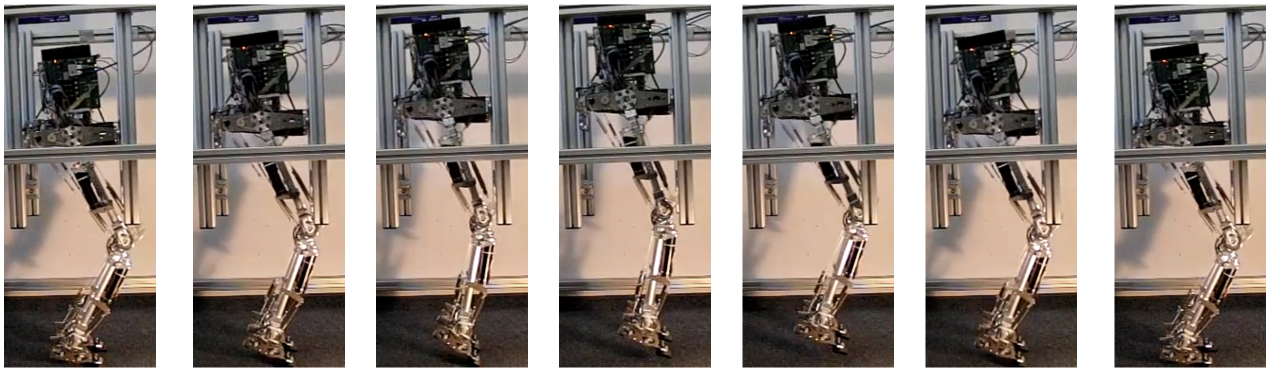
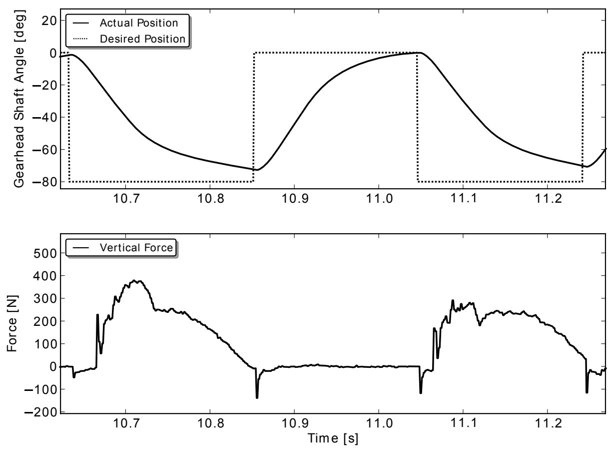


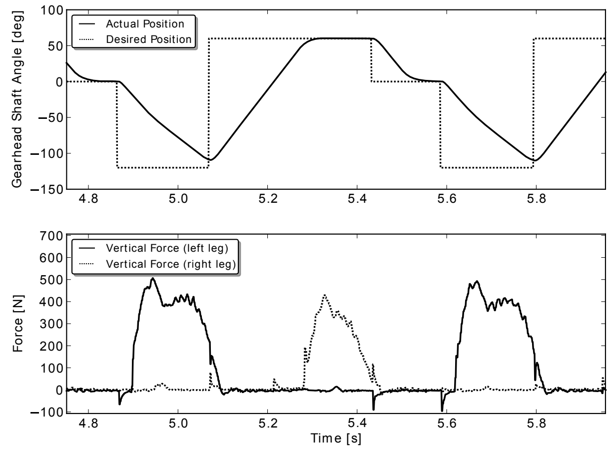
Fig. 2 Snapshots of one cycle of synchronous hopping motion. The robot pelvis motion is constrained to a 1D vertical translational degree of freedom by the surrounding frame.

sitions switched periodically between two set points, corresponding to configurations with retracted and extended legs, for synchronous hopping (Fig.3(a)). The same strategy was used for alternate hopping, with the addition of a third set point corresponding to an intermediate position in preparation for touchdown (Fig.3(b)). The hip pitch motor was controlled to result in a "free motion" (no torque applied) of the hip pitch joint. Additional springs were used to stabilize the leg configuration during aerial phase (a pair at the hip and one antagonist to the knee and ankle extensors). With this approach, hopping motions could be achieved in both cases with performances matching those of human for similar tasks (flight phase duration up to 200 ms leading to an average duty factor $\simeq 0.5$ (Fig.3) and ground clearance of up to 5 cm). The corresponding videos are available here: [7].

These preliminary results validate the robot design, as they demonstrate its ability to support high forces and impacts during the landing and to produce the required power to initiate and sustain hopping motions, a prerequisite for the realization of running. Further investigations will address intraleg coordination (for example, the influence of biarticular structures and the role of sensory feedback) to enhance leg operation and the realization of running by introducing fore and back swinging of the leg.



(a) synchronous hopping motion



(b) alternate hopping motion

Fig. 3 For each type of hopping motion: (Up) Set points (dotted line) and actual position (solid line) of the knee motor. (Down) Force measured by the forefoot force sensors with axis perpendicular to the foot sole.

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