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Author(s)	Gönen, Emre Cemal; Badri-Spröwitz, Alexander
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Towards Pitch-Free Control of an Underactuated and Compliant Bipedal Robot

Emre Cemal Gönen[1], Alexander Badri-Spröwitz[1,2]
[1]Max Planck Institute for Intelligent Systems, Stuttgart, Germany
[2]Department of Mechanical Engineering, KU Leuven, Belgium
gonen@is.mpg.de, sprowitz@is.mpg.de

1 Introduction

Biological inspiration can provide valuable pointers to engineers as starting seeds for the design of robot mechanics and control. BirdBot-1 robot (Fig. 1) took inspiration from the leg joint motion and anatomy of large birds [1]. BirdBot robot's mechanism mimicked the foot-mediated engagement and disengagement of the leg's muscular-tendon network, and it demonstrated highly energy-efficient legged locomotion. While BirdBot-1 used a pitch-fixed trunk, we are now aiming to develop a new, pitch-free bipedal robot. We foresee two interconnected challenges; to stabilize the pitch-motion of the trunk of a bipedal robot that is driven by compliant and underactuated legs.

The leg structure contains five links and five joints, and it is coupled by a global spring tendon (GST) connecting all leg joints (Fig. 2 Left). The global spring is mounted serially to the global tendon. It coordinates the motion of leg joints in the stance phase while it is slacked in the flexed position during the swing phase. The pantograph spring that connects Femur and Tarsometatarsus links exerts forces when the retraction torque is applied at the hip [2].

Our new BirdBot-robot version will integrate actuation and control to balance in 3D, whereas the control will be adapted to the specifics of BirdBot robot's legs. The BirdBot research showed that the robot's legs require ground clearance to rotate from digital-flexed to digital-extended while transitioning from swing to stance (Fig. 2 Center). Hence, a robot without external pitch-stabilization will require a high ground clearance; a forward-pitching trunk could reduce the clearance for a brief point in time. Therefore, a higher leg angular velocity enables the leg to reach its maximum forward leg angle earlier, which is the required posture for clutch initialization while generating higher clearance. In addition to the ground clearance, pitching moments should be reduced by supporting BirdBot's hip-powered actuation with an actuator-powered knee extension. Therefore, BirdBot's RC servo motors will be replaced by high-torque actuators from the SOLO-ODRI project (Fig. 2 Right) [3].

The control approach of our new pitch-free Birdbot will integrate successful implementations from previous research [4, 5]. Simplified linear models have been successfully used to generate walking patterns in real-time. Unlike exploiting the whole dynamics of a bipedal robot, they can capture the task-relevant dynamics to a set of linear equations. Therefore, the computation effort reduces considerably with this simplification. In this context, the Linear Inverted Pendulum Model (LIPM) has been successfully used for controlling complex bipedal robots [5]. Model predictive control (MPC) was introduced as an efficient tool for walking pattern generation using the LIPM [6, 7]. MPCs are well-suited for bipedal locomotion as they allow the controller to optimize control inputs over a finite horizon while incorporating constraints and system dynamics. Therefore, we will implement MPC to control the pitch-free BirdBot. We expect that an MPC-based control system is able to handle a wide range of disturbances and uncertainties, including changes in terrain, unexpected forces, and measurement noise, which can occur due to underactuated and compliant leg structure.

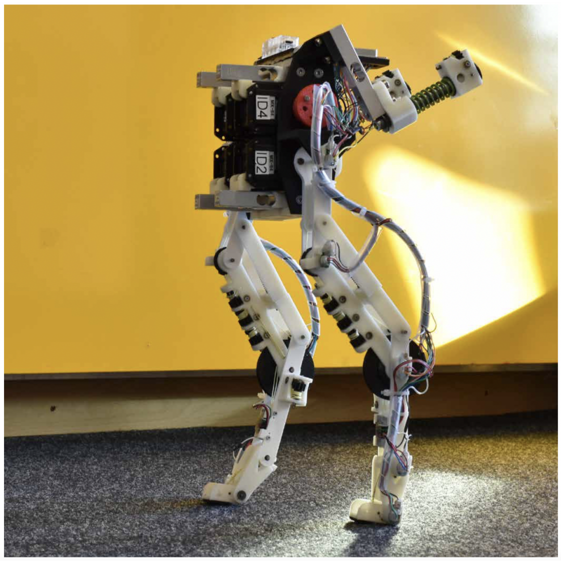

Figure 1: Overview of BirdBot-1 [1]. The robot was inspired by the lower legs of large birds having multijoint and elastic tendon mechanisms. A leg is actuated by two brushed motors. BirdBot can stand with its actuators turned off. The robot's body weight is supported by its leg mechanism, which is latched and engaged by its foot. The foot can serve as a practical point of pressure, where the center of mass can be placed.

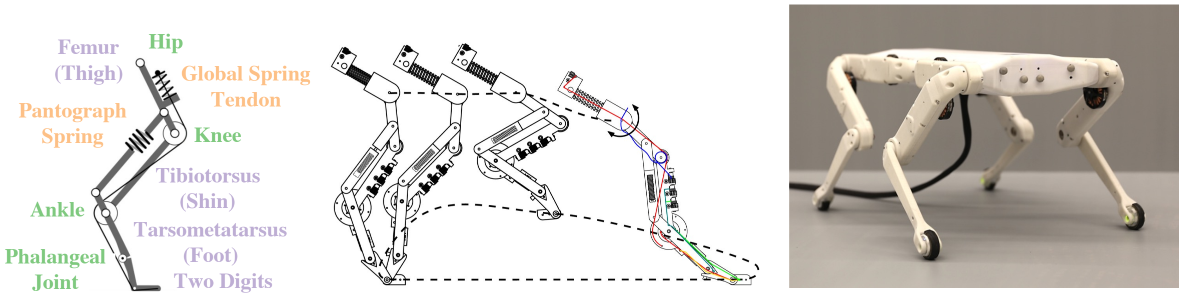

Figure 2: **Left:** Schematics of BirdBot [1]. Green labels indicate joint names, and purple ones show link names. Orange labels indicate springs. **Center:** Schematic of BirdBot's leg and foot trajectory over a gait cycle [1]. The leg needs ground clearance to rotate from digital-flexed to digital-extended while transitioning from swing to stance **Right:** The 2.2 kg quadruped robot, SOLO [3]. We aim to merge the BirdBot leg design with SOLO robot's brushless-motor actuator modules.

2 Future work and research questions

We aim to control a compliant, underactuated bipedal robot BirdBot without using external pitch support. The robot will feature high-torque density actuators to deliver power for dynamic trunk stabilizing motions rapidly. However, controlling the robot involves a number of difficulties, such as underactuation, compliance, and system stability. We will combine a linearized model with MPC to control slow- and medium-speed walking.

The control approach will be tested on a real robot outfitted with high-torque density actuators utilizing inverse dynamics. Researchers are also interested in investigating running, which would offer a more thorough grasp of the robot's capabilities and limitations.

We are currently implementing a model predictive controller with a linear inverted pendulum model for a fully actuated bipedal robot in the PyBullet simulation environment. As a next step, we will integrate BirdBot's specific tendon slack and compliance behavior in our simulated robot model. We will test the model at low- and mid-speed walking. At AMAM, we would like to take the opportunity to discuss both traditional and also novel concepts to control underactuated and compliant legs, improve the robustness of trunk stabilization, and how to integrate model predictive control with highly underactuated mechanisms.

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