Running robot Phides

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1 Introduction

Over the years, a number of hopping and running robots have been built to mimic the human running gait. However, most of these robots have a human-like gait or a human-like morphology, but not both. Examples of robots with a human-like gait, but without a human-like morphology, are the robots build by Raibert et al. [1]. These robots have a non-human-like telescopic leg, but gait characteristics that are close to the human running gait. Other examples of robots in this category are the ARL monopods by Ahmadi and Buehler [2] and the bowleg hopper by Zeglin and Brown [3]. On the other side are the robots with a human-like morphology, but without a human-like gait. These running robots are originally designed as ZMP walking robots. The most famous example of these robots is Honda's Asimo [4], which is able to run with speeds up to 9 km/h. Although this is an impressive achievement, the gait is far from human-like as it has a very short flight time. Other examples of robots in this category are Toyota's Partner Robot [5], HRP-2LR by Kaijta et al. [6], and Qrio by Nagasaka et al. [7].

Recently, the running robot Mabel by Grizzle et al. [8] has shown that it is possible to have a human-like gait on a robot with a human-like morphology. Here we present another running robot, which also has a human-like morphology and a human-like gait. This robot, called Phides and shown in Figure 1, has a number of similarities with Mabel, but has one big difference, its knee actuation. Phides knee actuation is special in that it has both a spring in series and a spring in parallel with the knee actuator.

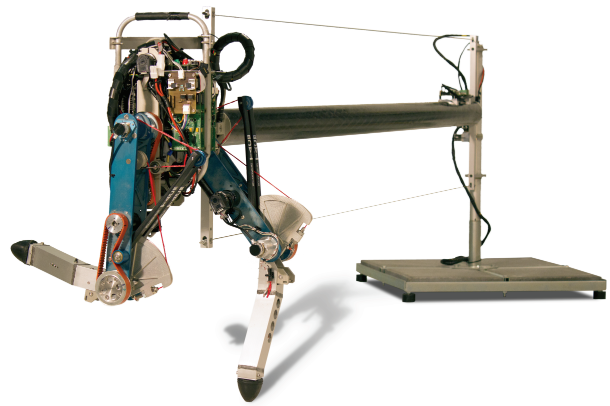

Figure 1: Running robot Phides, a robot with a human-like morphology and a human-like running gait.

2 Knee actuation design

Most running robots are equipped with a leg spring to store and release energy during the stance phase and with leg actuator to compensate for losses and to bend the leg during the swing phase. The leg actuator can be placed in series or in parallel with the leg spring. An advantage of placing the actuator in series with the leg spring is that impact forces are reduced due to the softening effect of the leg spring. Only, a disadvantage is that the actuator has to handle high forces when the leg is compressed, as all the spring force goes through the actuator. With the actuator in parallel with the spring, these high forces do not go through the actuator. However, with a parallel actuator there are high forces on the actuator at touchdown, as the actuator has to rapidly speedup. In addition, another disadvantage of a parallel actuator is that the actuator has to overcome the spring force to bend the leg during the swing phase.

For the knee design of Phides, we have chosen a hybrid solution to have the benefits of both options. In this design there is a spring in series as well as a spring in parallel with the actuation, as shown in Figure 2. The spring in series with the actuator is to prevent high impact forces on the actuator. In addition, the deflection of the series spring is measured and used to control the actuation torque as in a series elastic actuator [9].

The spring in parallel with the actuation is used to store and release energy during the stance phase. This parallel spring is connected to the knee joint by an actuated latching mechanism. The latching mechanism is used to detach the parallel spring at lift-off to permit free joint rotation during the flight phase, and attach it just before touchdown for energy storage during the stance phase. To keep some similarity with the SLIP model, we use non-constant transmission between the knee joint and the parallel spring to create an effective prismatic spring between the foot and the hip with constant stiffness. This non-constant transmission is designed to be changed easily as we plan to test the effect of the leg stiffness profile in the future.

3 Results

Figure 3 shows the torque of the actuator and the torque of the parallel spring during a running gait with a speed of about 1 m/s. The maximal torque on the knee joint is reached when the leg is maximal compressed and is about 90 Nm. Of this torque, 60 Nm comes from the parallel spring and 30 Nm from the actuator through the series spring. This indicates that the motor torques are a factor of 3 lower than when the actuator would be placed in series with the leg spring. In addition, the series spring seems to protect the motor, as figure 3 shows that there are also no high torques on the motor at touchdown.

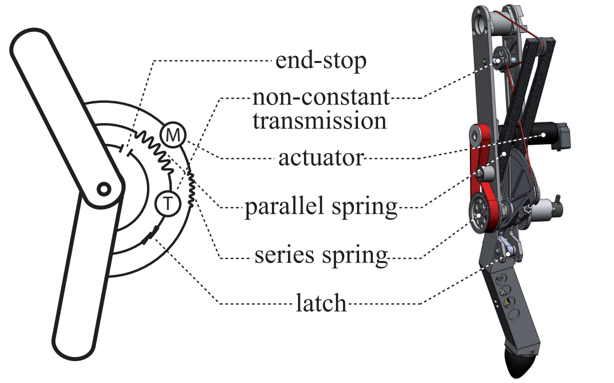

Figure 2: Schematic drawing and render of the knee joint. The parallel spring is constructed of fiberglass leaf springs from a crossbow and is connected to the knee joint by a transmission of non-circular pulleys and can be decoupled from the knee joint with a latching mechanism. The actuator is a brushed dc-motor that is connected to the knee joint by a series spring, which is a torsion bar inside the hollow knee shaft.

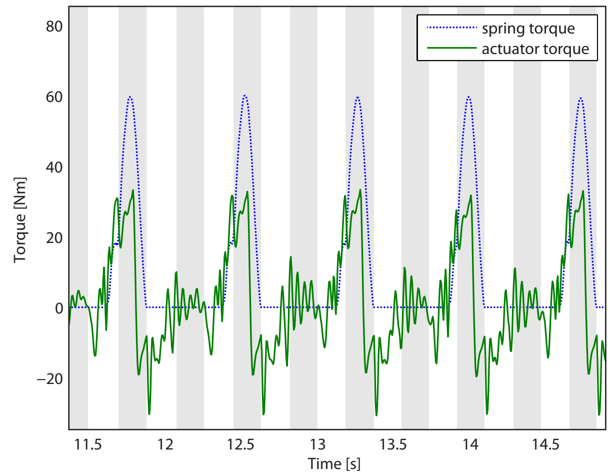

Figure 3: The torques on one knee joint during a running gait with a speed of about 1 m/s. The grey areas indicate the time that the robot is contact with the ground.

4 Discussion

The here presented knee actuation design has a great benefit in reducing the torque requirements of the actuator. However, it is a quite complex design, which requires a number of additional components. This complexity makes the system more sensitive to failure, as we found out when the connection between the torsion bar and the actuator broke. This raises the question if the benefit of reduced actuator torques outweighs the more complex design.

5 Future work

In the near future, we plan to use Phides to validate three simulation studies. The first simulation study to be validated is a study into the effects of swing leg retraction on energy efficiency and disturbance rejection [10, 11]. Next, a study will be validated in which the disturbance rejection of a number of foot placement strategies are compared. Finally, we will test the effect of non-linear leg stiffness on the disturbance rejection [12].

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