SoftFoot-Q: A Novel Adaptive Foot for Quadrupeds

M. J. Pollayil, M. G. Catalano, G. Grioli, A. Bicchi, *Fellow, IEEE,* and M. Garabini

***Abstract*—In this work, we present a novel prototype of soft adaptive foot, which is devised explicitly to be employed on quadrupedal robots. The SoftFoot-Q is a first step in the direction of favouring mechanically intelligent feet for robots and stresses the importance of moving towards haptic exploration of the environment through sensorized feet. These would lead to better algorithms for planning and control of locomotion that would improve robot stability. In the context of the EU project THING, the prototype is extensively tested and shows promising results.**

I. Introduction

Recent years have seen the remarkable growth of quadrupedal robotics. This is mainly due to the superior mobility that legged robots exhibit with respect to robots with wheels: the ability to decide where to place the feet reveals to be a big advantage, especially when it comes to locomotion on rough terrain [1]. However, this improved mobility comes at the expense of the requirement for an increased knowledge of the environment through (i) better sensing and (ii) improved feet design.

Traditionally, legged robotics has relied on the use of expensive sensors, such as LiDARs or 3D cameras, to get a reliable model of the surroundings in order to perform footstep planning and locomotion control. However, in the case of harsh operating conditions or while traversing uneven and challenging terrains, perceptual capabilities might degrade severely. Thus, there is a demand for enhanced perceptual capabilities of walking robots because traditional sensors might fail in harsh conditions [2].

By taking inspiration from how animals exploit various sensory elements in their feet and process the obtained information to achieve better locomotion [3], robotic feet can be enhanced with sensors that provide additional data about the terrain. These measurements can be fused with the ones obtained via traditional measurements to heighten the physical sense of the environment. Using the feet to explore the environment by physically interacting with it would advance the perception abilities of legged robots.

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Fig. 1: SoftFoot-Q, a soft adaptive foot for quadrupeds.

This notwithstanding, the idea of using feet as haptic probes is opposed to the simplistic shapes of currently employed feet for quadrupeds, which are either pointed or flat. These types of soles considerably narrow the sections of the terrain that can provide potentially stable footholds: this in turn reduces the possibility of foot-terrain interaction.

For this reason, another hindrance to be overcome is the reduced attention given to mechanical foot design in robotics. Especially in the field of quadrupedal robots, better feet design with inherent mechanical intelligence would definitely open the road to an even more wide-spread adoption of quadrupedal robots by improving the stability of locomotion on harsh terrains and by favouring environment exploration by means of haptic sensing.

II. SoftFoot-Q

To address the aforementioned issues, we developed a novel prototype of passive adaptive foot, the SoftFoot-Q, within the context of the EU Project THING. This project aims at empowering legged robots by reducing their dependency on vision-based sensors, thus widening the range of operation of these robots to more challenging settings, and by increasing their mobility, which would also open new possibilities for applications in the industry, such as inspection and monitoring of sewers and mines.

The proposed foot is very loosely based on the prototype foot for humanoids presented in [4] and is explicitly devised for quadrupedal robots. Some mechanical drawings are shown in Fig. 2. It is made of six main components: (A) an *ankle base* that is meant to be the connection interface with the robotic leg; (B) two *arch links* that create a plantar arch like structure; (C) two *roll links* that close the kinematic chain with (D) the *adaptive sole* of the feet. This last component is the core element of the foot design. It is in turn composed of four paddled chains that ensure a stiffening by compression behaviour: as the foot is placed on uneven terrain, because of the weight of the robot, the chains act like a rope in tension and adapt to the profile of the ground.

The foot prototype is made to be robust to interactions: the main links are made of aluminum and the chains are in stainless steel. This provides a shift toward a less fearful approach towards foot-terrain interaction, which is the key for haptic exploration of the environment. To this end, the foot is equipped with a sensing system.

Because of the requirements of robustness in very harsh environments, traditional sensors, such as joint encoders or force/torque sensors, cannot be employed on SoftFoot-Q. For the same reason, it makes no sense in using expensive measuring devices on the foot.

We propose to utilize Inertial Measurement Units (IMUs) as a low-cost sensing system in combination with efficient algorithms to estimate relevant quantities, such as joint angles or contact forces. The sensors are placed on the main links of the feet (except for the sole) in such a way that there are two IMUs in the links adjacent to each of the main joints. Moreover, the sensors are coated with a water resistant resin and covered by protective cases to make the system more robust to harsh conditions.

The ankle link of each foot has a case in which we place a custom electronic board, to which the IMUs are connected. A simplified schematic of the sensing system is provided in Fig. 3. The board reads the acceleration and angular velocities of each of the main links and processes the information also using simple algorithms. The measured and estimated data are then sent to the central PC of the robot through a ROS interface.

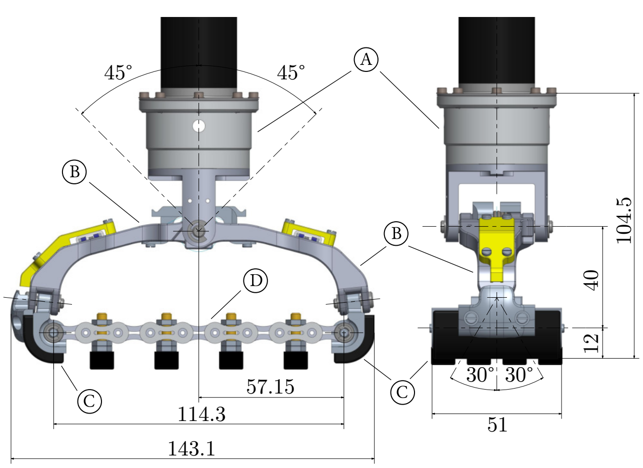


Fig. 2: Frontal and side views of the mechanical drawing of the SoftFoot-Q.

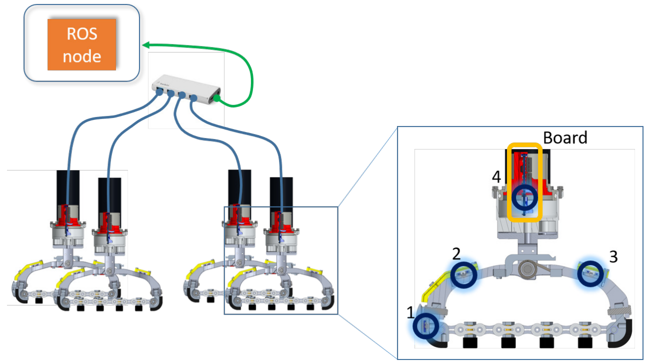
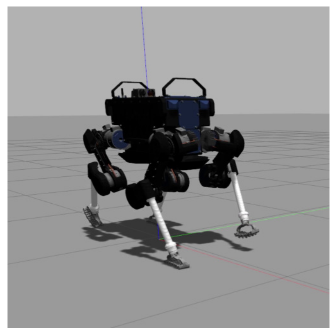


Fig. 3: A schematic of the sensing system of the SoftFoot-Q. Each foot provides a USB cable that can be connected to a PC to read the sensor measurements.


(a) Gazebo simulation


(b) Outdoor experiment

Fig. 4: SoftFoot-Q mounted and tested on ANYmal B.

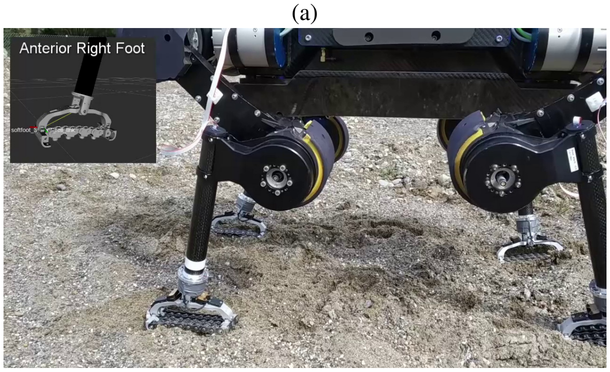
III. Results and Conclusions

Within Project THING, we tested the robot on the quadruped robot ANYmal B [5]. Preliminarily, a model of SoftFoot-Q was developed in Gazebo within ROS for simulating the feet on the robot. This was found to be a difficult task since the URDF format, used to describe robotic models in ROS, does not support closed kinematic chains. However, Gazebo supports them since it uses SDF, which is a different robot description language.

Together with the other partners of the project, we carried out extensive indoor and outdoor tests. The feet displayed high robustness and were found to increase the stability of locomotion in terms of slippage. No significant damage, both on the mechanical and the electronical sides, was reported.

A validation of the sensing system was also performed using a complimentary filter to reconstruct the joint angles and hence, the pose of the feet. Some photos of the outdoor experiments, in which the pose estimation was also used, can be seen in Fig. 5. We believe this to be a first step towards an extensive exploitation of haptic exploration in quadrupedal locomotion.

(a)



(b)

Fig. 5: Pose reconstruction during outdoor experiments.

Of course, more work needs to be carried out to fairly compare the performance of robots mounting traditional feet with the ones using SoftFoot-Q. For instance, locomotion control and planning algorithms that make use of the additional information provided by the sensing system should be devised. This is definitely part of future work. Also an actuated version of the foot, which would actively stabilize the foothold, is planned to be designed.

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