Chapter 10

Locomotion Interfaces for Legged Robots: Design Inspiration From Natural Locomotion Interfaces

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ABSTRACT

This chapter presents a comparative study of the topographical structure of three common biological robotic inspirations: human, canine, and feline feet. It is shown that the metrological roughness of each of the examined feet is customized for the specific locomotion demands of the species. The textural parameters manifest close correlation to the pressure distribution experienced in movement and gait. This correlation enhances the durability and structural integrity of the bio-analogue. It is also shown that the metrological function of the human (plantigrade) feet pads combine that of the back and the front feet pads of the digitigrade mammals examined. It is argued that integrating the targeted engineering of roughness within the design process of robotic feet can enhance the function of walking robots. Further, it offers elegant solutions to some of the current problems encountered in design of humanoids and other bio-inspired walking robots.

INTRODUCTION

Autonomous robotic systems comprise two main groups. The first is termed as manipulation robotics, whereas the second is referred to as mobile robotics. Mobile robotics are conventionally categorized in terms of their locomotion configuration. The first group is referred to as wheeled, legged, or crawling machines. Each of these locomotion configurations offer certain advantages that renders the particular robot class suitable for special applications. Each of the robotic classes have limitations as well. One limitation faced by wheeled and crawling robots is mobility in natural terrains. This disadvantage, however, is offset in legged robots.

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Locomotion Interfaces for Legged Robots

Legged robots offer superior mobility and they allow traversing difficult and inaccessible terrains. This is because their mode of locomotion, which uses legs, is advantageous in irregular terrains. Through varying the configuration of the legs, legged robots can selectively establish contact with the ground and adapt to surface irregularities. Legs also offer advantages in soft terrains (e.g., sand). The ability of selectively contacting the ground reflects positively on the energy consumption of the machine, improves stability, and widens the scope of applications. It is no surprise, therefore, that successful construction of legged robots have revolutionized application and utilization of robots in general.

Legged robots often mimic a biological model. Humanoids (which are biped machines) for example, mimic human locomotion (Hirai et al., 1998; Kaneko et al., 2008; Park et al., 2005; Radford et al., 2015; Kojima et al., 2015). Other machines are inspired by dinosaurs (Fukuoka and Akama, 2014), apes (Leong and Johnston, 2016), dogs (Tan et al., n.d; Sheba et al., 2018; Hunt, Szczecinski, and Quinn, 2017; He et al., 2019), cats (Kwon et al., 2015; Hayashi, Kato and Chobonyan, 2015; Liu et al., 2017; Duperyroux et al., 2017), insects (Koh et al., 2015; Szczecinski et al., 2015; Cardiaels et al., 2017), and reptiles (Gao et al., 2014; Yu et al., 2018; Luo et al., 2014; Vespignani et al., 2015; Tanaka and Tanaka, 2015; Liu et al., 2016), among other analogs. The field is growing rapidly and many biological examples are being studied for inspiration.

Mammalian locomotion stances may be classified in terms of the part of the foot engaging the ground while moving. Accordingly, three locomotion styles are typically mentioned in literature. The first is sole walking, termed as plantigrade, as that practiced by humans, bears and some species of apes. The second is the so-called digitigrade, which stands for toe walking (practiced by quadrupeds such as cats and dogs). The third class of locomotion is known as unguligrade, which denotes walking on nails or hoofs as in the case of horses and cattle.

The anatomy of mammals manifest differences that accommodate the diversity of their locomotion stances. Digitigrade and unguligrade animals differ than plantigrade animals in length and position of the structure comprising the foot-ankle assembly. The diversity of mammalian anatomy combined to their form of locomotion provide vast design possibilities for legged robots. A crucial step in the design of these machines is that of designing feet. Similar to their biological analog, efficiency of locomotion for the machines depends on optimizing the interaction between feet and the supporting ground. This interaction is influential to the gait of the machine and thereby the energetic cost of motion. It also affects posture, balance, and stability of the machine. The interaction between the feet the ground is twofold. First there is the biomechanical aspects of the motion of the foot, how the transfer must effort, relative motion of its parts, and generation forces while. The second concerns the interaction of the underfoot (i.e. the soles or the pads) with the ground. That is the actual interfacial contact with the ground and the mechanistic steps involved in force transmission.

Foot pads are an intrinsic component of the locomotor assemblies in mammals. They display a myriad of configurations, and form, all while reflecting universal composition. Regardless of the mammal, footpads are all composed of thick epidermal skin and subdermal adipose tissue permeated with fibrous septa (Raibert et al., 2008). This adipose tissue, which is essentially fat, is specialized. It does not respond to the physiological state of the animal, and instead of acting as a reservoir for energy, it serves structural purposes. Therefore, it is often termed as “structural adipose tissue” (Tenreiro and Silva, 2006). It follows that footpads are parts of the skin and they share many of the mechanical, thermal, and