adjusted to prevent the resonance frequency of the blades from coinciding with the rotation frequency or harmonics.

In one embodiment, electroactive polymers of the present invention are disposed in footwear, such as a shoe, to vary the stiffness of one or more portions of the shoe. There is a wide range of functional stiffness and damping control applications for electroactive polymers in footwear. For example, electroactive polymers disposed in the heel of the shoe may be used to vary the stiffness of the heel. The stiffness may then be controlled or manipulated to affect locomotion for a person, such as to improve walking or running. Stiffness of the polymers may then be tuned to achieve a particular performance of the footwear desirable to an application or the characteristics of the wearer, such as a high stiffness for running or for use with a heavier person. Provided below are additional exemplary applications for electroactive polymers within footwear.

As the term is used herein, footwear generally refers to any covering or attachment for a foot. This may include walking shoes; running shoes; athletic shoes for a particular sport such as soccer shoes, football shoes, tennis shoes; fashion footwear including women's shoes of varying shapes and designs; sandals; snowshoes; boots such as work boots; impact protection footwear; ski and snowboarding boots; and so on. Common parts of footwear may include a sole, a heel, a toe portion, etc. One of skill in the art will recognize the wide array of footwear currently available, and the present invention is not intended to be limited to any the footwear examples provided herein for illustrative purposes.

In some designs, control electronics and transducers are configured to provide variable stiffness for one or more portions of a shoe, such as show **300** as shown in FIG. **6**. This may include varying the stiffness of different parts, such as the sidewalls of hightop footwear, or the upper portion of footwear affected by laces, of footwear **300** for different times of usage. For example, shoes for daily wear may have a heel that decreases in stiffness when the shoe is not being, e.g., when a person is relaxing at a desk, but increases when the shoe is being used, e.g., for locomotion. Air or fluid filled sacs having an exterior comprising an electroactive polymer that varies in stiffness may be disposed in a heel to vary stiffness as desired. As transducers of the present invention may be manufactured in a wide variety of custom shapes and designs, the configuration of an electroactive polymer transducer in a shoe will vary with design, as one of skill in the art will appreciate. Different portions of the shoe other than the heel may relax and increase in stiffness in this manner. In a specific embodiment, a transducer is employed to vary the stiffness provided by an insole disposed in the shoe. Stiffness of various portions of the shoe may also vary based on user preferences or sensed features of the environment, e.g., stiffness is controlled depending on ground conditions such as sand, asphalt, rocks, etc., or may vary based on the mode of locomotion, e.g., a different stiffness for walking than for running or resting. It is well-known that tuning the stiffness and damping of a shoe to accommodate for changes in stiffness and damping of the environment experienced while walking or running, for example, can enhance the efficiency of the locomotion.

Electrical power for the electroactive polymers disposed in a shoe may come from a variety of sources. In one embodiment, a battery or fixed power supply is provided in the footwear to provide electrical energy. In another embodiment, an electroactive polymer generator disposed in the footwear provides at least partial power to actuate an electroactive polymer. In some cases, the generator polymer may be the same as the polymer providing the variable stiffness. The mechanical power may be generated during heel strike (to expand a polymer) and relaxation process may correspond to a person lifting their foot after it has struck the ground. As the polymer relaxes, the voltage of the charge on the polymer film is increased. The increase in charge's electrical energy, as indicated by its higher voltage, on the polymer film is harvested to generated electrical energy. In another embodiment, a battery in electrical communication with the electroactive polymer provides at least partial power to actuate the electroactive polymer.

In another aspect, variable stiffness/damping systems of the present invention are well-suited for use in robotics. In a distributed robotic scheme, multiple links are used wherein each link has its own drive, thus allowing a separate control for each link; and therefore independent dexterity for the entire device. In this scheme, an actuator (polymer based or other) is often required to move and support distal links that each include the added mass of a downlink actuator. Lightweight electroactive polymer transducers that provide actuation, and stiffness control, are clearly advantageous over heavier conventional actuators. One of skill in the art will appreciate the value of light weight in robotics, particularly when the robotic links are required to move at high speeds.

The ability to modulate the stiffness and damping about a robotic joint also allows for the implementation of impedance control schemes. Such control schemes have been shown to enable tasks that require dexterity that is not available with conventional actuators, such as motors operating through non-backdrivable transmission elements. The electroactive polymer transducers more closely approximate the behavior of natural muscle. It is well-known that biological creatures use the variable stiffness capability of muscle to enhance dexterity or locomotion efficiency.

Another area, closely related to robotics is prosthetic or orthotic devices for humans or other animals. For example, a prosthetic arm could include actuators where the stiffness of the actuators is adjustable. it is well-known that humans and other biological creatures adjust the apparent stiffness depending on the task to be accomplished. An example of an orthotic device is a brace where the transducers provide damping of vibrations caused by tremors.

13. Conclusion

While this invention has been described in terms of several preferred embodiments, there are alterations, permutations, and equivalents that fall within the scope of this invention which have been omitted for brevity's sake. By way of example, although the present invention has been described in terms of several numerous applied material electrodes, the present invention is not limited to these materials and in some cases may include air or liquids as an electrode. In addition, although the stiffness and damping techniques have been described independently, it is understood that many of the techniques may be combined such as systems that implement both stiffness regime and open loop control. In other words, although the ability to control stiffness and damping has been described separately in most of the embodiments provided above, it will be apparent to those skilled in the art that one could simultaneously select the desired stiffness and damping. More generally, one could select the desired mechanical impedance. It is therefore intended that the scope of the invention should be determined with reference to the appended claims.

What is claimed is:

1. A system for providing a desired stiffness using an electroactive polymer transducer, the system comprising: