

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
25 October 2001 (25.10.2001)

PCT

(10) International Publication Number
WO 01/80284 A2

(51) International Patent Classification⁷: H01L

(21) International Application Number: PCT/US01/11329

(22) International Filing Date: 5 April 2001 (05.04.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/194,817 5 April 2000 (05.04.2000) US
09/828,496 4 April 2001 (04.04.2001) US

(71) Applicant (for all designated States except US): SRI INTERNATIONAL [US/US]; 333 Ravenswood Avenue, Menlo Park, CA 94025 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): KORNBLUH, Roy,

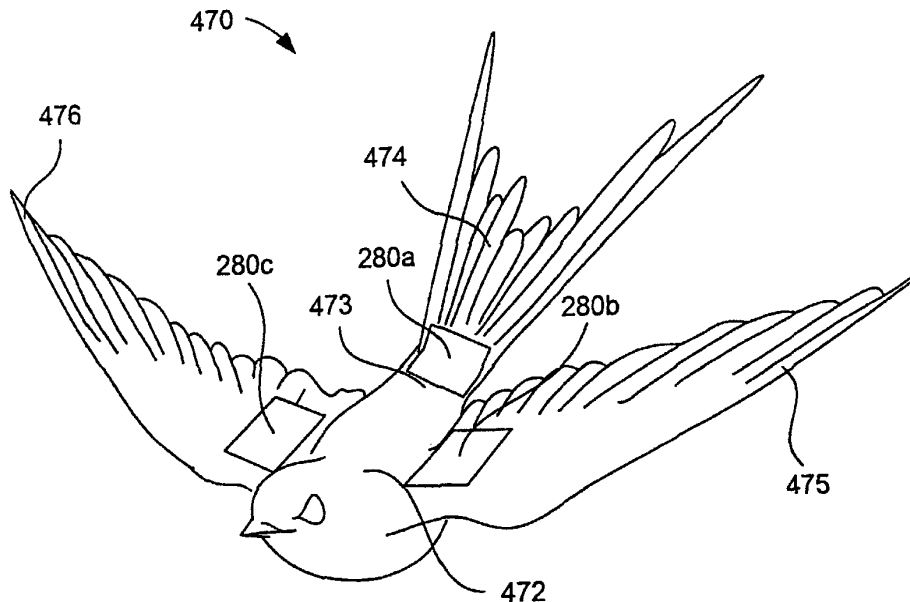
D. [US/US]; 260 Palo Alto Drive, Palo Alto, CA 94301 (US). PELRINE, Ronald, E. [US/US]; 180 Iroquois Drive, Boulder, CO 80303 (US). GALLAGHER, Paul [US/US]; 15110 Herring Avenue, San Jose, CA 95124 (US). ECKERLE, Joe [US/US]; Star Route, Box 20, Redwood City, CA 94025 (US). CZYZYK, Donald, E. [US/US]; 780 Los Padres Blvd., Santa Clara, CA 95050 (US). SHASTRI, Subramanian, Venkat [US/US]; 4373 Miller Avenue, Palo Alto, CA 94306 (US). PEI, Qibing [US/US]; 46170 Paseo Padre Parkway, Fremont, CA 94539 (US).

(74) Agent: WEAVER, Jeffrey, K.; Beyer Weaver & Thomas, LLP, P.O. Box 778, Berkeley, CA 94704-0778 (US).

(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

[Continued on next page]

(54) Title: ELECTROACTIVE POLYMER ANIMATED DEVICES



(57) Abstract: The present invention relates to animated devices that include one or more electroactive polymer transducers. When actuated by electrical energy, an electroactive polymer produces mechanical deflection in one or more directions. This deflection may be used to produce motion of a feature included in an animated device. Electroactive polymer transducers offer customizable shapes and deflections. Combining different ways to configure and constrain a polymer, different ways to arrange active areas on a single polymer, different animated device designs, and different polymer orientations, permits a broad range of animated devices that use an electroactive polymer transducer to produce motion. These animated devices find use in a wide range of animated device applications.



WO 01/80284 A2



(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

ELECTROACTIVE POLYMER ANIMATED DEVICES

BACKGROUND OF THE INVENTION

The present invention relates generally to animated devices comprising one or more electroactive polymers. More particularly, the present invention relates to animated devices having motion powered by electroactive polymer transducers, and their use in various applications such as toys and animatronics.

An animatronic device is an animated device with motion likeness of a human, creature, or animal. Conventional animatronic devices include animatronic puppets, robots, creatures, special effects make-up, scenic props, sets, etc. These devices find wide use in themed rides, dark walks, scenery, and special effects for the film and television industries.

Motion for an animatronic device is typically powered by an electric or mechanical source. The most common source of power for an animatronic device is electric motors such as AC, DC, servo, and stepper motors. Compressed air and pressurized hydraulic fluid are also used to power air and hydraulic motors in larger animatronic devices. Each of these forms of power has advantages and disadvantages that determines its usage.

AC and DC motors provide continuous rotary output, which is often not suitable for simple animatronic devices. For example, a simple animatronic device may require a lead screw and other mechanical assistance to convert continuous rotary output of a motor into simple linear motion. AC motors provide continuous rotary motion but are limited to a few speeds that are a function of the AC line frequency, e.g., 1800 and 3600 rpm based on 60 Hz in the U.S. If other outputs

speeds are desired for an animatronic device, a gearbox speed reducer is required; thus further complicating the animatronic device. Servomotors are fast response, closed loop control motors capable of providing programmed motion. In addition to the above rotary to linear complications, these devices are also very expensive.

5 Unlike servomotors, stepper motors are open loop, meaning they receive no feedback as to whether the output device has responded as requested. While being relatively good at holding an output in one position, stepper motors often are poor with motion, get out of phase with a desired control, moderately expensive, require special controllers, and thus not ideal for many animatronic devices.

10 Air and hydraulic motors have more limited application in animatronics than electric motors since they require the availability of a compressed air or hydraulic source. The additional weight, complexity and relative inefficiency of the power source makes these devices unsuitable for many animatronic applications, particularly for small mobile devices, since extremely small compressors and valves are currently
15 unobtainable. Although individual air motors and air cylinders are relatively cheap, these pneumatic systems are also quite expensive when the cost of all the ancillary equipment is considered.

In addition to the specific drawbacks discussed with respect to each source of power, all of the above systems are generally heavy, bulky and not suitable for many
20 applications where light weight and small size is desirable. Conventional electromagnetic technologies also typically do not have sufficient energy densities (the work output on a per volume or per mass basis) to construct many animatronic devices. The deficiency of many conventional devices is greater at small scales. As electromagnetic devices are scaled-down in size, their efficiency decreases. Further,
25 the above technologies provide strict mechanical output. Many animatronic applications require a high degree of mobility or dexterity that is difficult to achieve with conventional actuation technologies.

In view of the foregoing, alternative devices that convert from an input energy to mechanical energy would be desirable.

30

SUMMARY OF THE INVENTION

The present invention relates to animated devices that comprise one or more polymer based transducers. When a voltage is applied to electrodes contacting an electroactive polymer, the polymer deflects. Deflection of the transducer may then be converted into motion of a feature included in an animated device. Electroactive polymer transducers enable complex and customized animatronic devices by overcoming many of the actuator limitations described above. In this application, electroactive polymer transducers represent a simple, light weight, customizable, and efficient replacement for conventional actuators in animatronic devices.

In one aspect, the present invention relates to an animated device. The device comprises a feature capable of motion between a first position and a second position. The animated device also comprises a transducer configured to provide at least a portion of the motion between the first position and the second position for the feature. The transducer comprises an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer. The portion is capable of deflection in response to a change in electric field provided by the at least two electrodes.

In another aspect, the present invention relates to an animated face. The face comprises a facial feature capable of motion between a first position and a second position. The face also comprises a transducer configured to provide at least a portion of the motion between the first position and the second position for the facial feature. The transducer comprises an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer. The portion capable of deflection in response to a change in electric field provided by the at least two electrodes.

In yet another aspect, the present invention relates to an animated toy. The toy has a feature capable of motion between a first position and a second position. The animated toy also comprises a transducer configured to provide at least a portion of the motion between the first position and the second position. The transducer comprising an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer. The portion capable of deflection in response to a change in electric field provided by the at least two electrodes.

In still another aspect, the present invention relates to an animated skin. The animated skin comprises a feature capable of motion between a first position and a second position. The animated skin also comprises a transducer configured to provide at least a portion of the motion between the first position and the second position for the feature. The transducer comprises an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer. The portion is capable of deflection in response to a change in electric field provided by the at least two electrodes.

In another aspect, the present invention relates to an animated device. The animated device has a feature capable of motion between a first position and a second position. The animated device comprises a transducer configured to provide at least a portion of the motion between the first position and the second position for the feature. The transducer comprises an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer. The portion is capable of deflection in response to a change in electric field provided by the at least two electrodes. The animated device also comprises a sensor.

In yet another aspect, the present invention relates to an animated device. The animated device has a feature capable of motion between a first position and a second position. The animated device comprises a transducer configured to provide at least a portion of the motion between the first position and the second position for the feature. The transducer comprising an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer, the portion capable of deflection in response to a change in electric field provided by the at least two electrodes. The animated device also capable of acoustic emission.

In still another aspect, the present invention relates to an animated device capable of surface based locomotion. The animated device has a feature capable of motion between a first position and a second position. The animated device comprises a transducer configured to provide at least a portion of the motion between the first position and the second position for the feature. The transducer comprises an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer, the portion capable of deflection in response to a change in electric field provided by the at least two electrodes. The device is configured such

that motion between the first position and the second position for the feature provides at least a portion of the surface based locomotion.

In another aspect, the present invention relates to a doll. The doll comprises a body comprising a torso having a pair of arms extending therefrom, a head, a pair of legs extending downwardly therefrom, a neck portion supporting the head. The doll also comprises a transducer configured to move a feature on the doll. The transducer comprises an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer. The portion capable of deflection in response to a change in electric field provided by the at least two electrodes.

In yet another aspect, the present invention relates to an animated device having likeness of a human and a feature capable of motion between a first position and a second position. The animated device comprises a transducer configured to provide at least a portion of the motion between the first position and the second position for the feature. The transducer comprises an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer. The portion capable of deflection in response to a change in electric field provided by the at least two electrodes. The feature has a human likeness.

These and other features and advantages of the present invention will be described in the following description of the invention and associated figures.

20

BRIEF DESCRIPTION OF THE DRAWINGS

FIGs. 1A and 1B illustrate a top perspective view of a transducer before and after application of a voltage in accordance with one embodiment of the present invention.

25

FIG. 1C illustrates a cross-sectional side view of a diaphragm transducer including an electroactive polymer before application of a voltage in accordance with one embodiment of the present invention.

FIG. 2A and 2B illustrate a linear motion actuator suitable for use with some animated devices of the present invention.

30

FIG. 2C illustrates cross-sectional side view of a multilayer actuator suitable for use with some animated devices of the present invention.

FIGs. 2D and 2E illustrate an actuator suitable for use some animated devices of the present invention.

FIG. 2F illustrates a cross-sectional side view of a diaphragm actuator before application of a voltage in accordance with one embodiment of the present invention.

5 FIG. 2G illustrates a cross-sectional view of the diaphragm actuator of FIG. 2F after application of a voltage in accordance with one embodiment of the present invention.

FIGs. 2H and 2I illustrate a bending beam actuator suitable for use with some animated devices of the present invention.

10 FIGs. 3A-B illustrate an animatronic face in accordance with one embodiment of the present invention.

FIGs. 3C-D illustrate an animatronic eye in accordance with one embodiment of the present invention.

15 FIGs. 3E-F illustrate an animatronic face in accordance with another embodiment of the present invention.

FIG. 3G illustrates a toy dog in accordance with one embodiment of the present invention.

FIG. 3H illustrates leg assembly for the toy dog of FIG. 3G in accordance with a specific embodiment of the present invention.

20 FIG. 3I illustrates leg assembly in accordance with another specific embodiment of the present invention.

FIG. 3J-L illustrate a toy bird in accordance with another embodiment of the present invention.

25 FIG. 3M illustrates a front perspective view of a toy doll constructed in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

30 The present invention will now be described in detail with reference to a few preferred embodiments thereof as illustrated in the accompanying drawings. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one

skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process steps and/or structures have not been described in detail in order to not unnecessarily obscure the present invention.

5

1. OVERVIEW

The present invention relates to animated devices that include one or more electroactive polymers. When actuated by electrical energy, an electroactive polymer produces mechanical deflection. Deflection of the electroactive polymer transducer
10 may be used to produce motion of a feature of an animated device. The feature may be a leg or other body part included in an animated toy, for example. Electroactive polymer transducers offer customizable deflections by arranging one or more active areas on a single polymer and offer customizable shapes, e.g., rolls, diaphragms, etc. Multiple polymers may be included in a device by stacking or otherwise combining
15 individual polymers. Combining different ways to arrange a polymer in a device, different polymer actuators, different ways to arrange active areas on a single polymer and different animated device designs, permits a broad range of animated devices that use an electroactive polymer to produce motion. These animated devices find use in a wide range of animated device applications.

20 As the term is used herein, an animated device refers to a device, figure or object that simulates motion of a living organism or a portion of an organism. Exemplary animated devices include animatronic devices, toys, masks, mannequins, displays, scenic and entertainment industry set decorations, novelty items. etc. Typically, the animated device is designed or configured to seem alive or moving or
25 has some form of lifelike movement. In one embodiment, the devices are configured to simulate human actions and movements. This also includes non-living objects that simulate life-like characteristics, e.g., tea cups having actuated facial features that simulate talking. As mentioned above, an animatronic device is one class of animated device with motion likeness of a human, creature, or animal.

30

2. GENERAL STRUCTURE OF ELECTROACTIVE POLYMERS

The transformation between electrical and mechanical energy in devices of the present invention is based on energy conversion of one or more active areas of an electroactive polymer. Electroactive polymers deflect when actuated by electrical energy. To help illustrate the performance of an electroactive polymer in converting electrical energy to mechanical energy, FIG. 1A illustrates a top perspective view of a transducer portion 100 in accordance with one embodiment of the present invention. The transducer portion 100 comprises an electroactive polymer 102 for converting between electrical energy and mechanical energy. In one embodiment, an electroactive polymer refers to a polymer that acts as an insulating dielectric between two electrodes and may deflect upon application of a voltage difference between the two electrodes. Top and bottom electrodes 104 and 106 are attached to the electroactive polymer 102 on its top and bottom surfaces, respectively, to provide a voltage difference across a portion of the polymer 102. Polymer 102 deflects with a change in electric field provided by the top and bottom electrodes 104 and 106. Deflection of the transducer portion 100 in response to a change in electric field provided by the electrodes 104 and 106 is referred to as actuation. As polymer 102 changes in size, the deflection may be used to produce mechanical work.

FIG. 1B illustrates a top perspective view of the transducer portion 100 including deflection in response to a change in electric field. In general, deflection refers to any displacement, expansion, contraction, torsion, linear or area strain, or any other deformation of a portion of the polymer 102. The change in electric field corresponding to the voltage difference applied to or by the electrodes 104 and 106 produces mechanical pressure within polymer 102. In this case, the unlike electrical charges produced by electrodes 104 and 106 attract each other and provide a compressive force between electrodes 104 and 106 and an expansion force on polymer 102 in planar directions 108 and 110, causing polymer 102 to compress between electrodes 104 and 106 and stretch in the planar directions 108 and 110.

In some cases, electrodes 104 and 106 cover a limited portion of polymer 102 relative to the total area of the polymer. This may be done to prevent electrical breakdown around the edge of polymer 102 or to achieve customized deflections for one or more portions of the polymer. As the term is used herein, an active area is defined as a portion of a transducer comprising polymer material 102 and at least two

electrodes. When the active area is used to convert electrical energy to mechanical energy, the active area includes a portion of polymer 102 having sufficient electrostatic force to enable deflection of the portion. As will be described below, a polymer of the present invention may have multiple active areas. In some cases, polymer 102 material outside an active area may act as an external spring force on the active area during deflection. More specifically, polymer material outside the active area may resist active area deflection by its contraction or expansion. Removal of the voltage difference and the induced charge causes the reverse effects.

Electrodes 104 and 106 are compliant and change shape with polymer 102. The configuration of polymer 102 and electrodes 104 and 106 provides for increasing polymer 102 response with deflection. More specifically, as the transducer portion 100 deflects, compression of polymer 102 brings the opposite charges of electrodes 104 and 106 closer and the stretching of polymer 102 separates similar charges in each electrode. In one embodiment, one of the electrodes 104 and 106 is ground.

In general, the transducer portion 100 continues to deflect until mechanical forces balance the electrostatic forces driving the deflection. The mechanical forces include elastic restoring forces of the polymer 102 material, the compliance of electrodes 104 and 106, and any external resistance provided by a device and/or load coupled to the transducer portion 100, etc. The deflection of the transducer portion 100 as a result of the applied voltage may also depend on a number of other factors such as the polymer 102 dielectric constant and the size of polymer 102.

Electroactive polymers in accordance with the present invention are capable of deflection in any direction. After application of the voltage between the electrodes 104 and 106, the electroactive polymer 102 increases in size in both planar directions 108 and 110. In some cases, the electroactive polymer 102 is incompressible, e.g. has a substantially constant volume under stress. In this case, the polymer 102 decreases in thickness as a result of the expansion in the planar directions 108 and 110. It should be noted that the present invention is not limited to incompressible polymers and deflection of the polymer 102 may not conform to such a simple relationship.

In one embodiment, electroactive polymer 102 is pre-strained. Pre-strain of a polymer may be described, in one or more directions, as the change in dimension in a

direction after pre-straining relative to the dimension in that direction before pre-straining. The pre-strain may comprise elastic deformation of polymer 102 and be formed, for example, by stretching the polymer in tension and fixing one or more of the edges while stretched. For many polymers, pre-strain improves conversion
5 between electrical and mechanical energy. The improved mechanical response enables greater mechanical work for an electroactive polymer, e.g., larger deflections and actuation pressures. In one embodiment, prestrain improves the dielectric strength of the polymer. In another embodiment, the pre-strain is elastic. After actuation, an elastically pre-strained polymer could, in principle, be unfixed and
10 return to its original state. The pre-strain may be imposed at the boundaries using a rigid frame or may also be implemented locally for a portion of the polymer.

In one embodiment, pre-strain is applied uniformly over a portion of polymer 102 to produce an isotropic pre-strained polymer. For example, an acrylic elastomeric polymer may be stretched by 200 to 400 percent in both planar directions.
15 In another embodiment, pre-strain is applied unequally in different directions for a portion of polymer 102 to produce an anisotropic pre-strained polymer. In this case, polymer 102 may deflect greater in one direction than another when actuated. While not wishing to be bound by theory, it is believed that pre-straining a polymer in one direction may increase the stiffness of the polymer in the pre-strain direction.
20 Correspondingly, the polymer is relatively stiffer in the high pre-strain direction and more compliant in the low pre-strain direction and, upon actuation, more deflection occurs in the low pre-strain direction. In one embodiment, the deflection in direction 108 of transducer portion 100 can be enhanced by exploiting large pre-strain in the perpendicular direction 110. For example, an acrylic elastomeric polymer used in the
25 transducer portion 100 may be stretched by 100 percent in direction 108 and by 500 percent in the perpendicular direction 110. The quantity of pre-strain for a polymer may be based on the polymer material and the desired performance of the polymer in an application. Pre-strain suitable for use with the present invention is further described in copending U.S. Patent Application No. 09/619,848, which is
30 incorporated by reference for all purposes.

Generally, after the polymer is pre-strained, it may be fixed to one or more objects. Each object is preferably suitably stiff to maintain the level of pre-strain

desired in the polymer. The polymer may be fixed to the one or more objects according to any conventional method known in the art such as a chemical adhesive, an adhesive layer or material, mechanical attachment, etc.

Transducers and polymers of the present invention are not limited to any particular shape, geometry, or type of deflection. For example, a polymer and electrodes may be formed into any geometry or shape including tubes and rolls, stretched polymers attached between multiple rigid structures, stretched polymers attached across a frame of any geometry - including curved or complex geometries, across a frame having one or more joints, etc. Deflection of a transducer according to the present invention includes linear expansion and compression in one or more directions, bending, axial deflection when the polymer is rolled, deflection out of a hole provided on a substrate, etc. Deflection of a transducer may be affected by how the polymer is constrained by a frame or rigid structures attached to the polymer. In one embodiment, a flexible material that is stiffer in elongation than the polymer is attached to one side of a transducer to induce bending when the polymer is actuated.

Materials suitable for use as a pre-strained polymer with the present invention may include any substantially insulating polymer or rubber (or combination thereof) that deforms in response to an electrostatic force or whose deformation results in a change in electric field. One suitable material is NuSil CF19-2186 as provided by NuSil Technology of Carpinteria, CA. Other exemplary materials suitable for use as a pre-strained polymer include silicone elastomers such as those provided by Dow Corning of Midland, Michigan, acrylic elastomers such as VHB 4910 acrylic elastomer as produced by 3M Corporation of St. Paul, MN, polyurethanes, thermoplastic elastomers, copolymers comprising PVDF, pressure-sensitive adhesives, fluoroelastomers, polymers comprising silicone and acrylic moieties, and the like. Polymers comprising silicone and acrylic moieties may include copolymers comprising silicone and acrylic moieties, polymer blends comprising a silicone elastomer and an acrylic elastomer, for example. Combinations of some of these materials may also be used as the electroactive polymer in transducers of this invention.

An electroactive polymer of the present invention may have a wide range of thicknesses. In one embodiment, polymer thickness may range between about 1

micrometer and 2 millimeters. Polymer thickness may be reduced by stretching the film in one or both planar directions. In many cases, electroactive polymers of the present invention may be fabricated and implemented as thin films. Thicknesses suitable for these thin films may be below 100 micrometers.

5 Suitable actuation voltages for electroactive polymers, or portions thereof, may vary based on the material properties of the electroactive polymer (e.g., dielectric constant) and the dimensions of the polymer (e.g., polymer film thickness). For example, actuation electric fields used to actuate polymer 102 in FIG. 1A may range in magnitude from about 0 V/m to about 440 MV/m. Actuation electric fields
10 in this range may produce a pressure in the range of about 0 Pa to about 10 MPa. In order for the transducer to produce greater forces, the thickness of the polymer layer may be increased. Actuation voltages for a particular polymer may be reduced by increasing the dielectric constant, decreasing the polymer thickness, and decreasing the modulus of elasticity, for example.

15 Generally, electrodes suitable for use with the present invention may be of any shape and material provided that they are able to supply a suitable voltage to an electroactive polymer. The voltage may be either constant or varying over time. In one embodiment, the electrodes adhere to a surface of the polymer. As electroactive polymers of the present invention may deflect at high strains, electrodes attached to
20 the polymers should also deflect without compromising mechanical or electrical performance. Correspondingly, the present invention may include compliant electrodes that conform to the changing shape of an electroactive polymer to which they are attached. The electrodes may be only applied to a portion of an electroactive polymer and define an active area according to their geometry. In many cases, such
25 as the pupil described below with respect to FIG. 3C, the shape of the electrode provides substantial simulation of a feature in an animated device.

 Various types of electrodes suitable for use with the present invention are described in copending U.S. Patent Application No. 09/619,848, which was previously incorporated by reference above. Electrodes described therein and
30 suitable for use with the present invention include structured electrodes comprising metal traces and charge distribution layers, textured electrodes comprising varying out of plane dimensions, conductive greases such as carbon greases or silver greases,

colloidal suspensions, high aspect ratio conductive materials such as carbon fibrils and carbon nanotubes, and mixtures of ionically conductive materials.

Materials used for electrodes of the present invention may vary. Suitable materials used in an electrode may include graphite, carbon black, colloidal
5 suspensions, thin metals including silver and gold, silver filled and carbon filled gels and polymers, and ionically or electrically conductive polymers. In a specific embodiment, an electrode suitable for use with the present invention comprises 80 percent carbon grease and 20 percent carbon black in a silicone rubber binder such as Stockwell RTV60-CON as produced by Stockwell Rubber Co. Inc. of Philadelphia,
10 PA. The carbon grease is of the type such as NyoGel 756G as provided by Nye Lubricant Inc. of Fairhaven, MA. The conductive grease may also be mixed with an elastomer, such as silicon elastomer RTV 118 as produced by General Electric of Waterford, NY, to provide a gel-like conductive grease.

It is understood that certain electrode materials may work well with particular
15 polymers and may not work as well for others. For example, carbon fibrils work well with acrylic elastomer polymers while not as well with silicone polymers. For most transducers, desirable properties for the compliant electrode may include one or more of the following: low modulus of elasticity, low mechanical damping, low surface resistivity, uniform resistivity, chemical and environmental stability, chemical
20 compatibility with the electroactive polymer, good adherence to the electroactive polymer, and the ability to form smooth surfaces. In some cases, a transducer of the present invention may implement two different types of electrodes, e.g. a different electrode type for each active area or different electrode types on opposing sides of a polymer.

25 Electronic drivers are typically connected to the electrodes. The voltage provided to electroactive polymer will depend upon specifics of an application. In one embodiment, a transducer of the present invention is driven electrically by modulating an applied voltage about a DC bias voltage. Modulation about a bias voltage allows for improved sensitivity and linearity of the transducer to the applied
30 voltage.

Transducers of the present invention are also capable of acoustic emission. More specifically, transducers of the present invention may be actuated at frequencies to produce sound in a medium such as air. Thus, the same transducer responsible for actuation of a feature in an animated device may also be responsible for acoustic emission for the animated device. Typically, an audio signal is provided to electrodes in contact with the polymer such that sound waves are produced during rapid actuation and elastic contraction of the transducer. The signal may be a signal from a stereo player or microphone that has been amplified and converted to the correct voltage range. For example, a transducer used to provide acoustic emission may be driven by a signal of up to 200 to 1000 volts peak to peak on top of a bias voltage ranging from about 750 to 2000 volts DC. However, it will be appreciated that the particular voltages used may vary based on the parameters of an application. Further description of electroactive polymer transducers used to produce sound is described in commonly owned, co-pending U.S. Patent Application entitled "Elastomeric Dielectric Polymer Film Sonic Actuator" naming R. E. Pelrine et al. as inventors, filed on July 19, 1999 (U.S. Application No. 09/356,801), which is incorporated herein for all purposes.

Although the discussion so far has focused primarily on one type of electroactive polymer commonly referred to as dielectric elastomers (transducer 100 of FIG. 1A), animated devices of the present invention may also incorporate other conventional electroactive polymers. As the term is used herein, an electroactive polymer refers to a polymer that responds to electrical stimulation. Other common classes of electroactive polymer suitable for use with many embodiments of the present invention include electrostrictive polymers, electronic electroactive polymers, and ionic electroactive polymers, and some copolymers. Electrostrictive polymers are characterized by the non-linear reaction of a electroactive polymers (relating strain to E^2). Electronic electroactive polymers typically change shape or dimensions due to migration of electrons in response to electric field (usually dry). Ionic electroactive polymers are polymers that change shape or dimensions due to migration of ions in response to electric field (usually wet and contains electrolyte). Irradiated copolymer of polyvinylidene difluoride and trifluoroethylene P(VDF-TrFE) is an electroactive polymer suitable for use with some embodiments of the present invention.

3. MULTIPLE ACTIVE AREAS

In accordance with the present invention, the term “monolithic” is used herein to refer to electroactive polymers, transducers, and devices comprising a plurality of active areas on a single electroactive polymer.

5 FIG. 1C illustrates a monolithic transducer 150 comprising a plurality of active areas in accordance with one embodiment of the present invention. The monolithic transducer 150 converts between electrical energy and mechanical energy. The monolithic transducer 150 comprises an electroactive polymer 151 including two active areas 152a and 152b. The polymer 151 can be held using, for example, a rigid
10 frame (not shown) attached at the edges of the polymer 151.

The active area 152a has top and bottom electrodes 154a and 154b attached to the polymer 151 on its top and bottom surfaces 151c and 151d, respectively. The electrodes 154a and 154b provide a voltage difference across a portion 151a of the polymer 151. The portion 151a deflects with a change in electric field provided by
15 the electrodes 154a and 154b. The portion 151a comprises the polymer 151 between the electrodes 154a and 154b and any other portions of the polymer 151 having sufficient electrostatic force to enable deflection upon application of voltages using the electrodes 154a and 154b.

The active area 152b has top and bottom electrodes 156a and 156b attached to
20 the polymer 151 on its top and bottom surfaces 151c and 151d, respectively. The electrodes 156a and 156b provide a voltage difference across a portion 151b of the polymer 151. The portion 151b deflects with a change in electric field provided by the electrodes 156a and 156b. The portion 151b comprises the polymer 151 between the electrodes 156a and 156b and any other portions of the polymer 151 having
25 sufficient stress induced by the electrostatic force to enable deflection upon application of voltages using the electrodes 156a and 156b.

Active areas for monolithic polymers and transducers of the present invention may be flexibly arranged. In one embodiment, active areas in a polymer are arranged such that elasticity of the active areas is balanced. In another embodiment, a
30 transducer of the present invention includes a plurality of symmetrically arranged active areas. Further description of monolithic transducers suitable for use with the

present invention are further described in commonly owned U.S. Patent Application No. 09/779,203, which is incorporated by reference herein for all purposes.

4. ACTUATOR DESIGNS

5 The deflection of an electroactive polymer can be used in a variety of ways to produce mechanical energy. One common implementation of a transducer in an animated device is within an actuator. Generally speaking, animated devices of the present invention may be implemented with a variety of actuators - including conventional actuators retrofitted with a polymer and custom actuators specially
10 designed for one or more polymers. Conventional actuators include extenders, bending beams, stacks, diaphragms, etc. Several different exemplary actuators suitable for use with some animated devices of the present invention will now be discussed.

 A straightforward electroactive polymer drive is one where the transducer acts
15 as a linear actuator in much the same way as a conventional pneumatic or hydraulic cylinder might be employed. FIGs. 2A-2E illustrate several linear electroactive polymer actuators suitable for use with the present invention.

 The shape and constraint of an electroactive polymer may affect deflection. An aspect ratio for an electroactive polymer is defined as the ratio of its length to
20 width. If the aspect ratio is high (e.g., an aspect ratio of at least about 4:1) and the polymer is constrained along its length by rigid members, then the combination may result in a substantially one-dimensional deflection in the width direction.

 FIG. 2A and 2B illustrate a linear motion actuator 230 suitable for use with devices of the present invention. The linear motion actuator 230 is a planar
25 mechanism having mechanical deflection in one direction. The linear motion actuator 230 comprises a polymer 231 having a length 233 substantially greater than its width 234 (e.g., an aspect ratio at least about 4:1). The polymer 231 is attached on opposite sides to stiff members 232 of a frame along its length 233. The stiff members 232 have a greater stiffness than the polymer 231. The geometric edge constraint
30 provided by the stiff members 232 substantially prevents displacement in a direction

236 along the polymer length 233 and facilitates deflection almost exclusively in a direction 235. When the linear motion actuator 230 is implemented with a polymer 231 having anisotropic pre-strain, such as a higher pre-strain in the direction 236 than in the direction 235, then the polymer 231 is stiffer in the direction 236 than in the direction 235 and large deflections in the direction 235 may result.

A collection of electroactive polymers or actuators may be mechanically linked to form a larger actuator with a common output, e.g. force and/or displacement. By using a small electroactive polymer as a base unit in a collection, conversion of electric energy to mechanical energy may be scaled according to an application. By way of example, multiple linear motion actuators 230 may be combined in series in the direction 235 to form an actuator having a cumulative deflection of all the linear motion actuators in the series.

FIG. 2C illustrates cross-sectional side view of a multilayer actuator 240 for converting from electrical energy to mechanical energy. The multilayer actuator 240 includes four pre-strained polymers 241 arranged in parallel and each attached to a rigid frame 242 such that they have the same deflection. Electrodes 243 and 244 are deposited on opposite surfaces of each polymer 241 and are in electrical communication such that they provide simultaneous electrostatic actuation to the four pre-strained polymers 241. The multilayer actuator 240 provides cumulative force output of the individual polymer layers 241. In one embodiment, electrodes 243 and 244 are arranged to provide separate actuation for each polymer 241. In this manner, one may use on-off voltage control actuation of each polymer 241. This arrangement provides a user relatively simple control of force magnitude for the multilayer actuator 240. the the

FIGs. 2D and 2E illustrate a linear actuator 300 suitable for use some animated devices of the present invention. The actuator 300 includes a polymer 302 arranged in a manner which causes a portion of the polymer to deflect in response to a change in electric field. Electrodes 304 are attached to opposite surfaces (only the foremost electrode is shown) of the polymer 302 and cover a substantial portion of the polymer 302. Two stiff members 308 and 310 extend along opposite edges 312 and 314 of the polymer 302. Flexures 316 and 318 are situated along the remaining

edges of the polymer 302. The flexures 316 and 318 improve conversion from electrical energy to mechanical energy for the actuator 300.

The flexures 316 and 318 couple polymer 302 deflection in one direction into deflection in another direction. In one embodiment, each of the flexures 316 and 318 rest at an angle about 45 degrees in the plane of the polymer 302. Upon actuation of the polymer 302, expansion of the polymer 302 in the direction 320 causes the stiff members 308 and 310 to move apart, as shown in FIG. 2E. In addition, expansion of the polymer 302 in the direction 322 causes the flexures 316 and 318 to straighten, and further separates the stiff members 308 and 310. In this manner, the actuator 300 couples expansion of the polymer 302 in both planar directions 320 and 322 into mechanical output in the direction 320.

One advantage of the actuator 300 is that the entire structure is planar. In addition to simplifying fabrication, the planar structure of the actuator 300 allows for easy mechanical coupling to produce multilayer designs. By way of example, the stiff members 308 and 310 may be mechanically coupled (e.g., glued or similarly fixed) to their respective counterparts of a second actuator 300 to provide two actuators 300 in parallel in order to increase the force output over single actuator 300. Similarly, the stiff member 308 from one actuator may be attached to the stiff member 310 from a second actuator in order to provide multiple actuators in series that increase the deflection output over a single actuator 300.

In another embodiment, electroactive polymers suitable for use the present invention may be rolled or folded into linear transducers and actuators that deflect axially while converting from electrical energy to mechanical energy. As fabrication of electroactive polymers is often simplest with fewer numbers of layers, rolled actuators provide an efficient manner of squeezing large layers of polymer into a compact shape. Rolled or folded transducers and actuators typically include two or more layers of polymer. Rolled or folded actuators are applicable wherever linear actuators are used, such as legs and fingers, high force grippers, or some of the animated designs described below.

FIG. 2F-G illustrate a cross-sectional side view of a monolithic diaphragm actuator 130 comprising a monolithic polymer 131 before deflection in accordance

with one embodiment of the present invention. The polymer 131 is attached to a frame 132. The frame 132 includes apertures 133a and 133b that allow deflection of polymer portions 131a and 131b perpendicular to the area of the apertures 133a and 133b, respectively. The diaphragm device 130 comprises electrodes 134a and 134b attached on either side of the portion 131a to provide a voltage difference across the portion 131a. Electrodes 136a and 136b are deposited on either side of the portion 131b to provide a voltage difference across the portion 131b. The electrodes 134 and 136 are compliant and change shape with polymer 131 as it deflects. In the voltage-off configuration of FIG. 2F, polymer 131 is stretched and secured to frame 132 with tension to achieve pre-strain.

Using electrodes 134 and 136, portions 131a and 131b are capable of independent deflection. For example, upon application of a suitable voltage between electrodes 134a and 134b, portion 131a expands away from the plane of the frame 132, as illustrated in FIG. 2G. Each of the portions 131a and 131b is capable of expansion in both perpendicular directions away from the plane. In one embodiment, one side of polymer 131 comprises a bias pressure that influences the expansion of the polymer film 131 to continually actuate upward in the direction of arrows 143 (FIG. 2G). In another embodiment, a swelling agent such as a small amount of silicone oil is applied to the bottom side to influence the expansion of polymer 131 in the direction of arrows 143. The swelling agent allows the diaphragm to continually actuate in a desired direction without using a bias pressure. The swelling agent causes slight permanent deflection in one direction as determined during fabrication, e.g. by supplying a slight pressure to the bottom side when the swelling agent is applied. The swelling agent allows the diaphragm to continually actuate in a desired direction without using a bias pressure.

FIG. 2H illustrates a bending beam actuator 280 suitable for use with animated devices of the present invention. The bending beam actuator 280 includes a polymer 281 fixed at one end by member 282 and attached to a flexible thin material 283 such as polyimide or mylar using an adhesive layer, for example. The flexible thin material 283 has a modulus of elasticity greater than the polymer 281. The difference in modulus of elasticity for the top and bottom sides 286 and 287 of the bending beam actuator 280 causes the bending beam actuator 280 to bend upon

actuation. Electrodes 284 and 285 are attached to the opposite sides of the polymer 281 to provide electrical energy. The bending beam actuator 280 includes a free end 288 having a single bending degree of freedom. Deflection of the free end 288 may be measured by the difference in angle between the free end 288 and the end fixed by the rigid support 282. FIG. 2I illustrates the bending beam actuator 280 with a 90 degree bending angle. The maximum bending angle for the bending beam actuator 280 will vary with a number of factors including the polymer material, the actuator length, the bending stiffness of the electrodes 284 and 285 and flexible thin material 283, etc.

Although FIGs. 2A-2I illustrate several actuators suitable for use with motors of the present invention, other actuators including one or more electroactive polymers may also be used. Other exemplary actuators include bending beam actuators, diaphragm actuators and inchworm actuators are also suitable for use with the present invention. Additional exemplary linear and non-linear actuators suitable for use with the present invention are described in commonly owned U.S. Patent Application Application No. 09/619,848, which was previously incorporated by reference.

5. ANIMATED DEVICES

5.1 EXEMPLARY ANIMATED DEVICES

Electroactive polymer transducers are well-suited for use in animatronic devices such as animatronic faces. FIGs. 3A-B illustrate front and back perspective views, respectively, of an animatronic face 400 in accordance with one embodiment of the present invention. The face 400 is made from a polymer mold 402 of silicone rubber and is fabricated according to conventional silicone rubber molding techniques. Attached on the inside of the mold 402 are a series of actuators 404a-e. Each of the actuators 404a-e comprise a transducer having an electroactive polymer 403 and electrodes attached on opposing surfaces of the electroactive polymer 403. The polymer mold 402 is flexible and changes shape with deflection of the actuators 404a-e. The flexibility of the polymer may be controlled so that the motion occurs primarily in certain regions of interest. This control may be accomplished by molding the polymer thinner in certain areas. A relatively rigid frame with hinged

joints may also be incorporated beneath the polymer to ensure that motion only occurs between specific regions of the polymer.

Each actuator 404 is responsible for providing motion of a separate feature of face 400. In one embodiment, each actuator 404 is a linear actuator similar to the linear actuator of FIGs. 2D and 2E and has opposing rigid members 407 attached to mold 402. The rigid members 407 translate deflection of each electroactive polymer transducer into motion of a feature for the face 400. For example, actuator 404e has upper and lower rigid members 405a and 405b that are attached above and below a mouth 416.

Referring to the outer appearance of the face 400 (FIG. 3A), actuation and deflection of actuator 404a vertically opens right eye 406. When electrical energy is removed from actuator 404a, elastic return of electroactive polymer 403a included in actuator 404a, and elastic return of the mold 402, return right eye 406 to its resting position. Similarly, deflection of actuator 404b vertically opens a left eye 408. When electrical energy is removed from actuator 404b, elastic return of mold 402 and electroactive polymer 403b return left eye 408 to its resting position. Deflection and elastic return of actuators 404c and 404d provide motion for right and left cheeks 412 and 414, respectively. Deflection and elastic return of actuator 404e provides motion for mouth 416.

Actuators 404a-e are capable of independent actuation and may be individually or collectively used to simulate motion of a human face. For example, independent actuation of actuator 404e may be used to simulate mouth 416 movements corresponding to speech for the face 400. As electroactive polymers are capable of independent and complex time varying deflections, controlled actuation of multiple actuators 404a-e may be used to simulate complicated motions such as those that simulate human emotion. In a specific embodiment, independent actuation of actuators 404a-d are used to provide facial expressions that correspond emotionally to speech provided by mouth 416. For example, actuators 404a and 404b may both be actuated to open both eyes 406 and 408, thereby simulating surprise for face 400. The degree of surprise may be varied by differing the speed and displacement magnitude of actuation of actuators 404a and 404b. Eyebrows 418 may also accentuate the effect of displacement and human-like simulation provided by

actuators 404a and 404b. Alternatively, actuators 404c and 404d may be simultaneously actuated to simulate a human smile. The type of smile, or degree of emotion conveyed by the smile, may be varied by differential actuation of the actuators 404c and 404d. As one skilled in animatronics will appreciate, controlled actuation of actuators 404a-e may be performed in a variety of ways to convey emotion and facial expressions for face 400.

Actuator 404e is configured such that the polymer included therein is capable of producing sound. In this case, the same transducer may be used for both actuation of mouth 416 and acoustic emission. When actuation and acoustic emission is performed simultaneously, the audio signal is superimposed on an actuation signal. The actuation is distinguished from the acoustic emission signal largely by frequency. The acoustic signal is typically of much higher frequency and lower magnitude than the lower frequency actuation signal. This high-frequency signal will have little effect on the resultant motion. In many cases, a DC bias is included with the high-frequency acoustic signal. This DC bias will produce a small amount of actuator motion which is usually acceptable. Often the acoustic emission is done at the same time as the actuation. In this case, the bias may be part of the actuation signal (linearly superimposed). The magnitude of the acoustic signal may be scaled such that the magnitude of the acoustic response is of the desired frequency profile, regardless of the magnitude of the actuation signal.

Additional humanlike motions may be applied to the face 400 using other animatronic devices used in conjunction with face 400. FIGs. 3C-D illustrate an animatronic eye 425 in accordance with one embodiment of the present invention. Eye 425 is a planar transducer having electrodes 426 patterned on opposite sides of polymer 427. Polymer 427 is attached on its perimeter to a frame 428. Frame 428 allows attachment to the inner surface of polymer 402 of face 400 in regions 424 near each eye. Eye 425 need not be flat. In another embodiment, eye 425 comprises a polymer stretched over a convex surface. The surface may be a slippery material that allows polymer 427 to slide over it. A lubricant may also be disposed between polymer 427 and the convex surface. A suitable lubricant might be a petroleum oil in the case of acrylic materials. This approach could also be used in allowing many of

the facial motions described above to move over a convex surface rather than operate in at a flat plane.

Electrodes 426 cover a central circular portion of polymer 427, are dark and opaque, and thus resemble a human eye pupil. Actuation using electrodes 426 (attached on both sides of the film) causes polymer 427 in the region of electrodes 426 to expand in the plane. Electrodes 426 change shape with polymer 427. Thus, planar expansion of polymer 427 increases the darkened surface area of electrodes 426 and simulates dilation of a pupil, as illustrated in FIG. 3D. Portions of the polymer 427 outside the active area corresponding to electrodes 426 provide a contractile resistance to actuation. To enhance aesthetic appeal, polymer 427 material not covered by electrodes 426 may be colored white. When used with face 400, dilation and contraction of the electrodes 426 may be used to contribute to the simulation of human emotions by face 400. For example, actuation of eye 425 may be in conjunction with actuation of actuators 404a and 404b to simulate surprise for face 400.

FIGs. 3E-F illustrate front and back perspective views, respectively, of animatronic face 430 in accordance with another embodiment of the present invention. Face 430 comprises a monolithic transducer including polymer 432 and electrode pairs 434, 436, 438, and 442 attached to outer and inner surfaces 431a and 431b of polymer 432 (e.g., 434a on inner surface 431a and 434b on outer surface 431b). Thus, polymer 432 is a monolithic polymer comprising four active areas that provide independent deflections and motions for the face 430. Polymer 431 comprises silicone rubber that is molded into a shape that provides the outer aesthetic appearance for face 430. In one embodiment, polymer 432 is relatively thin and has a thickness in the range of about 0.020 to about 0.10 millimeters.

Each electrode pair 434, 436, 438, 440, and 442 is responsible for actuation of a separate portion of the polymer 431 to produce motion for a separate feature for face 430. Actuation of electrode pair 434 moves right (FIG. 3E) eyebrow 441 down. Actuation of electrode pair 436 moves left eyebrow 443 down. Actuation of electrode pair 442 closes mouth 445. When electrical energy is removed from electrode pairs 434, 436, and 442, elastic return of polymer 432 returns each feature 441, 443, and 445 to its resting position before actuation. Electrode pairs 438 and

440 are patterned on the right and left cheek areas of face 430, respectively, to provide active areas that expand out of the plane similar to the monolithic diaphragm actuator described in FIGs. 2F and 2G. Actuation of the active area 438 may be used to simulate the bulging of the right cheek for face 430. Actuation of the active area 5 442 may be used to simulate the bulging of the left cheek. In one embodiment, a swelling agent such as a small amount of silicone oil is applied to the inner side 431b of polymer 431 to influence outward expansion of polymer 431. As one skilled in animatronics will appreciate, electrodes may be arranged on polymer mold 432 in a variety of ways to established desired skin deformations, provide controlled facial 10 expressions, and convey emotions for face 430.

Electrode pairs 434, 436, 438, 440, and 442 are arranged with separate electrical communication. Independence of the electrode pairs allows electrical energy to be separately supplied to different portions of the polymer; thus allowing independent control for each of the active areas. Independent control may include 15 deflection at different times, rates, and degrees of deflection. In another embodiment, two or more electrodes for face 430 are electrically coupled, e.g., electrode pairs 434 and 436 to allow for common actuation of eyebrows 441 and 443.

The electroactive polymer 432 exploits the flexibility of the electroactive polymer material as well as the ability to fabricate structures with high degrees of 20 freedom by patterning multiple electrode pairs on a single polymer. In one embodiment, electrode pairs are patterned on polymer mold 432 to simulate facial features and facial muscle of a human. These simulated facial muscles may then be used to provide motion for features of the face 432 that simulates human facial movements. As one of skill in the art will appreciate, there are an abundant number 25 of facial features, facial muscles, facial movements, and facial expressions that may be simulated using individual or multiple dedicated active areas on an electroactive polymer.

While the face 430 is illustrated as having a symmetrical appearance, it is understood that animated faces and devices of the present invention may comprise 30 multiple active areas having a non-symmetrical and custom geometries. It is also understood that active areas may be combined in any configuration. These custom geometry active areas and configurations may be used, alone or a combination, to

produce any custom two-dimensional deflection. In some cases, two active areas responsible for motion of separate features may be actuated together to provide movement for a separate portion of face 430 not specifically associated with the features associated with each of the active areas. For example, simultaneous
5 actuation of electrode pairs 434 and 436 may also cause polymer material between the active areas in the central forehead region 439 to raise with eyebrows 441 and 443. It is also contemplated that elastic return may be used to provide controlled deflection. Similar to simultaneous actuation, elastic return of one portion of the polymer 432 corresponding to first active area may be combined with actuation of a
10 second active area to provide a specialized movement for face 430, e.g., to provide movement for a separate portion of face 430 not specifically associated with the features associated with each of the active areas

In one embodiment, polymer 432 is substantially thin and flexible, and may be attached conformably to solid structures having flat and curved surfaces as if polymer
15 432 is an external skin. Face 430 then takes the shape of the structure that it is fixed to. Non-fixed portions are then be capable of motion as determined by active areas arranged on polymer 432. As described above, face 430 may be partially attached to a convex surface that allows motion for features communicating with an electroactive polymer transducer. The convex surface would then allow for non-linear motion of
20 the flexible polymer 432 about the convex surface. As illustrated in FIGs. 3E-F, electrode pairs are deposited on both sides, outward and hidden, of face 430. To hide opaque or unsightly electrode pairs on the outside and showing surface of the face 430, a cosmetic outer skin may cover the face 430. The outer cosmetic skin may be made of polyurethane, pigmented silicone rubber or natural latex rubber, for example.
25 In another embodiment, the outer surface of polymer 432 is painted to hide the outer electrodes.

In another aspect, electroactive polymer transducers of the present invention are used in toys. FIG. 3G illustrates a top perspective view of toy dog 450 in accordance with one embodiment of the present invention. Frame 465 (FIG. 3H)
30 provides structural support for dog 450. Skin 467 is attached to frame 465 and provides an outer cover that protects internal components and provides an aesthetic appearance. Dog 450 is capable of legged surface based locomotion and includes

four leg assemblies 452a-d powered by one or more electroactive polymer transducers.

FIG. 3H illustrates a cutaway side view of leg assembly 452a showing the leg assembly inside skin 467 in accordance with a specific embodiment of the present invention. Leg assembly 452a is a two degree of freedom structure having a first-
5 degree freedom about pin 453 and a second degree of freedom about pin 454. Pin 453 is fixed to frame 465 of toy dog 450.

A first transducer 455 operates against a bias spring 456 to provide rotational motion between lower member 461 and upper member 463 of leg assembly 452a.
10 Transducer 455 is a linear transducer rotably coupled to a central portion of lower member 461 at one end and rotably coupled to a central portion of upper member 463 at its opposite end. Bias spring 456 provides a counterclockwise bias force for leg 457 about pin 454 that maintains a resting position for leg 457 when transducer 455 is not actuated. As shown, actuation of transducer 455 rotates the lower member 461 of
15 leg 457 clockwise about pin 454 to push lower member 461 down. When electricity is removed from transducer 455, elastic energy stored in bias spring 456 rotates lower member 461 counterclockwise and returns leg 457 to its resting position.

A second transducer 459 operates against a bias spring 450 to provide rotational motion between the upper member 463 of leg assembly 452a and frame
20 465. Transducer 459 is a linear transducer rotably coupled to a central portion of upper member 463 and rotably coupled to frame 465 at its opposite end. As shown, actuation of transducer 459 rotates upper member 463 clockwise about pin 453 to move leg 457 backwards. When electricity is removed from transducer 459, elastic energy stored in bias spring 450 moves leg 457 forward and returns leg 457 to its
25 lateral resting position.

Together, transducer 455 and transducer 459 may be used to provide two degree of freedom motion for any part of lower member 461. Thus, transducers 455 and 459 may be used to contribute to a legged locomotion trajectory for a distal portion of leg 457. Leg assembly 452a may then be used in combination with other
30 similar leg assemblies to provide a legged locomotion for dog 450. For example, electrical energy is removed from transducer 455 to pick lower member 461 up, and

electrical energy is removed from transducer 459 to move lower member 461 and upper member 463 forward. In this case, elastic energy stored in springs 450 and 456 moves the distal end of leg 457 forward by rotating upper member 463 about pin 453 and lower member 461 about pin 454. At some point during forward displacement of leg 457, electrical energy is provided to transducers 459 and 455, bringing the distal portion of leg 457 down. Electrical energy may be provided either simultaneously or separately to provide a specific trajectory for the distal portion of leg 457. Leg 457 also includes padding 458 at its distal end attached to lower member 461. Padding 458 provides a compliant and larger area of contact with a surface that dog 450 is traversing to assist legged locomotion.

Although leg assembly 452a disk illustrated with transducers 459 and 455 providing clockwise rotation for their respective leg members about the pin joints as shown, it is understood that transducers 459 and 455 may each be oppositely coupled to their respective leg members in order to provide counterclockwise rotation for actuation of each transducer. In this case, activation of the polymer provides rotation in the opposite direction. One of skill in the art will appreciate that there are numerous trajectories that the distal end 461 can take in legged locomotion such as trajectories associated with walking, trotting, and running, for example. In a specific embodiment, springs 450 and 456 supply a constant force for deflection about each pin. Deflection about each pin may then follow a constant energy path to provide an energy efficient method for legged locomotion of dog 450. Deflection of an electroactive polymer using a constant energy path is described in further detail in commonly owned, pending U.S. Patent Application Number 09/779,373, which is incorporated by reference for all purposes.

Each transducer 455 and 459 is driven by a dc-dc converter with a maximum output of 5kV and 500 mW of power. A dc-dc converter suitable for use with transducers 455 and 459 is model Q50 as provided by EMCO High Voltage of Sutter Creek, CA. Actuation of transducers 455 and 459 may be initiated in a number of ways. In one embodiment, dog 450 includes a processor that coordinates actuation of transducers included in all four leg assemblies 452a-d. A processor, such as the PIC18C family of processors as provided by Microchip Technology Inc. of Chandler, Arizona, may be suitable to control each of the transducers 455 and 459 as well as

their respective dc-dc converters. The processor may be coupled to a switch or a depressible push button which the user actuates by squeezing a portion of dog 450. Dog 450 may also include a battery or other electrical storage device enclosed within frame 465 that provides electrical energy to transducers 455 and 459 and the
5 processor.

FIG. 3I illustrates a leg assembly 560 in accordance with another specific embodiment of the present invention. Leg assembly 560 is a one degree of freedom structure having a rotational degree freedom about brace 561. Brace 561 provides fixed attachment to a frame 465. Transducer 562 actuates antagonistically against
10 transducer 563. Both transducers 562 and 563 are attached at their proximate ends to member 564 and attached at their distal ends to frame 465. Member 564 rotates at its central portion 564a about brace 561 and has a free end 564b that is rotably coupled to leg 568. Member 567 provides torsional support for the leg assembly 560 and is rotably coupled at its proximate end to brace 561 and rotably coupled at its distal end
15 to leg 568. Together, transducers 562 and 563 control the vertical position of leg 568. Leg assembly 560 may include another transducer that controls lateral displacement of leg assembly 560.

FIG. 3J-L illustrate top perspective and front views of a toy bird 470 in accordance with another embodiment of the present invention. Bird 470 comprises a
20 body 472 having a neck 471 and supports a pair of legs 479. Bird 470 also comprises several bending beam actuators 280a-c. Each bending beam actuator 280 is attached at their proximate end to body 472 and provides motion for a feature of bird 470 relative to body 472.

Deflection of bending beam actuator 280a rotates tail feathers 474 about a
25 connection point 473 on body 472. Wings 475 and 476 are connected to distal ends of bending beam actuators 280b and 280c, respectively. In their resting position, wings 475 and 476 lie 180 degrees apart (FIG. 3K). Actuation of bending beam actuator 280b rotates wing 475 upward about body 472 (FIG. 3L). Actuation of bending beam actuator 280c rotates wing 476 upward about body 472. Thus,
30 actuation of bending beam actuators 280b and 280c causes wings 475 and 476 to rotate upwards towards each other as illustrated in FIG. 3L.

When electricity is removed from the electrodes included in actuator 280b, elastic energy of the polymer included in the actuator returns wing 475 to its resting position. A similar elastic return occurs for actuator 280c and wing 476. Electrical energy may be repeatedly provided to actuators 280b and 280c to simulate flapping and flying for bird 470.

In another embodiment, a thin transducer, comprising an electroactive polymer and electrodes, covers one of the wings 475 or 476. The thin transducer is custom patterned monolithically according to simulate the shape of feathers for the bird 470. The transducer may then be used to reconfigure the shape of each wing according to the pattern of electrodes to simulate cruising and evasive motions of birds in flight.

FIG. 3M illustrates a front perspective view of a hand held toy doll 500 constructed in accordance with another embodiment of the present invention. Doll 500 includes a body comprising a unitary torso 501 having a neck 503 supporting a head 502. Torso 501 further supports a pair of arms 504 and 505 and a pair of legs 506 and 507. Arms 504 and 505 are passive. Preferably arms 504 and 505 are somewhat pivotal in their attachment to torso 501 such that a user is able to induce motion of arms 504 and 505.

Legs 506 and 507 are also somewhat pivotal in their attachment to torso 501 and each capable of user movement relative to torso 501 about the attachment. In addition, each leg 506 and 507 includes an electroactive polymer transducer that simulates kicking motion for doll 500. More specifically, transducer 509 is configured on the anterior side of leg 506 and attached at one end to thigh portion 510 of leg 506 and attached at its opposite end to lower leg portion 511. Actuation of transducer 509 causes lower leg portion 511 to rotate about knee joint 512, thus providing motion for leg 506. Doll 500 may be provided with a ball. A user, in conjunction with actuation of transducer 509, may use doll 500 to simulate kicking of the ball.

Actuation of transducer 509 may be initiated in a number of ways. In one embodiment, the transducer 509 is coupled to a depressible push button which the user actuates by squeezing a portion of doll torso 501. The transducer 509 and

actuates when the depressible pushbutton is pushed or after the depressible pushbutton is released. In another embodiment, doll 500 includes a microphone and electric driving circuitry that allows voice activation of transducer 509. Doll 500 may also include a battery or electrical storage device enclosed within torso 501.

5 Transducer 509 is driven by a control circuit and dc-dc converter with an output of 5kV and 300 mW of power. A dc-dc converter suitable for use with transducer 509 is model Q50 as provided by EMCO High Voltage Inc. of Sutter Creek, CA.

Doll 500 is intended to meet the need for more interactive hand held dolls as opposed to more sophisticated dolls that operate on their own. In contrast, one of
10 skill in the art will appreciate that doll 500 may include numerous other electroactive polymer transducers that are processor controlled and designed to operate on their own without user assistance. Broadly speaking, one aspect of the present invention relates to articulated dolls including one or more electroactive polymer transducers. The dolls may be such devices employing an electroactive polymer that drives a
15 movement feature - that is manually activated or processor activated. Toy dolls are a well known segment of the toy industry. Thus, dolls have been provided which vary from large "life size" dolls to small fashion dolls. Further variation is found in the material of dolls varying from soft so-called "plush" dolls to hand held hard plastic dolls and doll figures. By way of further variation, dolls may be provided that vary
20 from simple dolls which have one or two moving features to dolls which are extremely active and able to perform various movements or activities.

While the doll 500 has been described specifically with respect to electroactive polymer transducers that provide motion that simulates kicking, it is understood that there a variety of other lifelike actions and movements that doll 500
25 may designed to simulate. Other exemplary lifelike actions whose movements an electroactive polymer transducer may contribute to simulation of include simulated skating action, liquid drinking action, swallowing action, smiling, arm waving, dancing, talking, throwing, blinking, burping, rolling over, etc. Lifelike movements that may be powered by an electroactive polymer transducer include may also any of
30 those associated with the human actions listed above and any movements associated with a specific body part. Exemplary head 503 movements relative to torso 501 include nodding, twisting and universal movement of the head relative to the torso.

In general, toys in accordance with one aspect of the present invention include any toy that simulates motion of a living organism or a portion of an organism, such as hand held dolls, stuffed and plush toys, articulated action figures, action figure accessories, preschool learning toys, preschool talking & sound toys, mechanical design kits, robotic/virtual pets, etc. Each toy and may use one or more electroactive polymer transducers to provide motion for limbs, body segments, or appendages such as wings, antennae, etc. Toys of the present invention comprising one or more electroactive polymer transducers may include animated games. Exemplary animated games include those that use electroactive polymer transducers to direct static devices into motion for game purposes (e.g., to move a ball into a hole) and fighting toys having movements powered by one or more electroactive polymers and controlled by a user. As will be described in further detail below, transducers included in the fighting toys may also comprise electroactive polymer transducers with sensor capabilities.

One manner of classifying the large number of toys having motion powered by electroactive polymers of the present invention is by the type of motion produced by electroactive polymer. In one embodiment, electroactive polymer animated devices correspond to toys having surface based locomotion such as ground based and/or gravity-assisted locomotion powered by one more electroactive polymer transducers. Exemplary surface based types of locomotion include legged locomotion (bipedal, multiple legged, walking, trotting, crawling, running, etc), hopping (e.g., rabbits, frogs, kangaroos, etc.), wheeled locomotion (e.g., cars, trains, bicycles), and slithering (e.g., snakes, snails, slugs, etc.). Other exemplary types of locomotion include swimming (fish, eels, etc.) and flying, flapping and soaring (e.g. birds, butterflies, dragonflies, aircraft, etc.

In another embodiment, electroactive transducer powered toy has mobility independent from its user, e.g., wheeled vehicles such as trains and cars, legged animals such as dogs and dinosaurs, battery operated vehicles, electric/battery car sets & accessories, etc. In some cases, the devices may include remote control that controls actuation and deflection of an electroactive polymer. One of skill in the art will appreciate the abundant number of robotic toys that may be designed including electroactive polymer transducer and remote control.

An animated device that employs an electroactive polymer transducer may be considered a direct drive device where the transducer directly translates into motion of the feature. In many cases, back drivability associated with electroactive polymers included in a direct drive devices is desirable for an application. As the term is used
5 herein, backdrivability refers to the ability to move a transducer against a direction of its actuation. Electroactive polymers typically have a low stiffness relative to their conventional electromechanical counterparts. More specifically, back drivability may be accomplished by overcoming the stiffness of the polymer during motion between a first position and a second position. This inherent low stiffness may provide a back
10 drivability that is advantageous in some applications. For example, should an animated device in a theme park accidentally contact an object during motion, motion may be stopped by overcoming the stiffness of the polymer. As a result, the shock and initial force would typically be low relative to conventional electromechanical actuation, potentially reducing the amount of force experienced by the object. Thus,
15 an animated device is in accordance with the present invention may be designed with a back drivability for motion of a feature between two positions. In one embodiment, the back drivability is accomplished by setting a maximum stiffness of polymer and device for motion of the feature between the first and second position.

In a specific embodiment, toys of the present invention comprise a feature that
20 is back drivable. Since electroactive polymers are inherently compliant as discussed, back drivability for the toy may be accomplished by overcoming the stiffness of the polymer during motion between one position, e.g., a resting position, and a second position, e.g., a position of actuation. In addition, polymer material may be selected based on the back drivability requirements of an application. Polymer that is more
25 compliant may add a larger compliance to the operation of an animatronic device by potentially reducing impact forces if an undesired collision occurs.

5.2 ANIMATED DEVICE OVERVIEW

Having briefly discussed several exemplary animated devices, some general
30 aspects that may apply to animated devices of the present invention will now be discussed. In general, an animated device in accordance with the present invention

comprises one or more electroactive polymers configured to provide motion for a feature of the device. The feature may be any portion of the device having motion at least partially contributed to by deflection (actuation or elastic return) of an electroactive polymer. There are an abundant number of animated device designs
5 suitable for use with the present invention - including conventional animated devices retrofitted with one or more electroactive polymers and custom animated devices specially designed for electroactive polymer usage. Since many electroactive polymer transducers can operate well over a large range of sizes with little change in performance, electroactive polymer powered animated devices have many potential
10 applications for both and large small devices.

An electroactive polymer may have customized deflections and strokes; thus permitting customized motions for a particular animated device. The use of multiple electroactive polymers in an animated device allows for the development of dextrous devices with numerous customized degrees of freedom. These customizable
15 deflections and strokes also provide power without the need for complex transmission mechanisms such as cables and gears, resulting in lightweight actuation that is ideal for small, compact, and lightweight animated devices. Since no complex transmission mechanisms are needed, the remainder of the animated device is typically less complex and expensive than conventional forms of actuation.

The simplicity and high-efficiency of electrical to mechanical energy
20 conversion provided by electroactive polymer transducers also allows improved animated devices in mobile and lightweight applications where available energy is limited. For example, mobile toys such as animated animals and remote control vehicles may benefit from the lightweight advantages of using an electroactive
25 polymer transducer. Since the transducer is substantially lighter than a conventional electromagnetic motor, and the need for complex transmission mechanisms is removed for many devices, less demanding electrical energy storage devices are required. For example, the lighter weight gained by using an electroactive polymer transducer allows a smaller battery to be used or the same size battery may be used
30 for a longer duration.

The present invention is also suitable for animated devices having a distributed transducer scheme. In a distributed transducer scheme, multiple links and

transducers are used wherein each transducer drives a link directly, thus allowing a specific control for each link and therefore greater dexterity for the entire device. For example, an animatronic mannequin may have separate electroactive polymer transducers that power an upper arm, lower arm, wrist, and individual fingers. In this scheme, lightweight transducers are advantageous since a transducer is often required to move and support distal links that each include the added mass of a downlink transducer. One of skill in the art will appreciate the value of light weight in robotics, toys, and animatronics devices having multiple links.

A collection of electroactive polymers or actuators may be mechanically linked to form a larger actuator with a common output, e.g. force and/or displacement. By using a small electroactive polymer as a base unit in a collection, conversion of electric energy to mechanical energy may be scaled according to an application. By way of example, multiple linear motion devices 230 (FIG. 2C) may be combined in series in the direction 235 to form an actuator having a cumulative deflection of all the linear motion devices in the series. Electroactive polymer transducers and actuators - either individually or mechanically linked in a collection - may be referred to as 'artificial muscle'. For purposes herein, an artificial muscle is defined as one or more transducers and/or actuators having a single output force and/or displacement. Artificial muscles may be implemented on a micro or macro level and may comprise any one or more of the transducers and actuators described herein.

Given the customizable shape of electroactive polymers, animatronic devices using electroactive polymer transducers may then be designed to mimic any natural muscle based organism. Duplication of natural muscle thus allows electroactive polymer transducer powered animated devices to produce many natural motions and dynamics related to living organisms; and thus animated devices based on these organisms. For example, the large stroke capability of electroactive polymers allows them to be used directly as linear actuators in much the same way as muscle is used in biological animals, e.g., a biceps muscle. Further, the performance of electroactive polymer transducers is largely scale invariant, e.g., independent of size or mass. One can readily see the advantage of artificial muscle transducers in animatronic devices by noting the many conventional biological analogs to highly articulated animatronic

devices that operate using muscular-like actuation. These include analogs such as fingers, hands, arms, legs, heads, limbs, body segments, wings, and appendages for a variety of insects and animals.

Animated devices of the present invention may also be designed and
5 configured such that a mechanical property of a transducer substantially simulates a mechanical property of a real muscle. Exemplary mechanical properties that may be simulated by an electroactive polymer include stiffness, stroke, shape, strain, pressure, speed of response, efficiency, compliance, modularity (transducers may be stacked in parallel or linked in series) damping, and bulging in the middle as the
10 muscle contracts. In one embodiment, electroactive polymer transducers are used to substantially simulate open loop or passive behavior of natural muscle. In this case, the transducers act as both a spring and damper in a passive manner similar to their natural counterparts.

15 5.3 SENSOR FUNCTIONALITY

Animated devices of the present invention may also include a sensor. The sensor may sense a quantity or item included in the device and/or sense a quantity or item detected from the environment around the device. Quantities sensed may include haptic, acoustic, visual, or kinesthetic feedback, for example. In one
20 embodiment, the sensor is a conventional sensor technology, e.g., a microphone or light sensor. In another embodiment, the sensor is an electroactive polymer transducer operating as a sensor.

FIGs. 1A and 1B may be used to show one manner in which the transducer portion 100 converts mechanical energy to electrical energy and acts as a sensor. If
25 the transducer portion 100 is mechanically stretched by external forces to a thinner, larger area shape such as that shown in FIG. 1B, and a relatively small voltage difference (less than that necessary to actuate the film to the configuration in Fig. 1B) is applied between electrodes 104 and 106, the transducer portion 100 will contract in area between the electrodes to a shape such as in FIG. 1A when the external forces
30 are removed. Once the transducer portion 100 is stretched, the relatively small voltage difference is provided such that the resulting electrostatic forces are

insufficient to balance the elastic restoring forces of the stretch. The transducer portion 100 therefore contracts, and it becomes thicker and has a smaller planar area in the plane defined by directions 108 and 110 (orthogonal to the thickness between electrodes). When polymer 102 becomes thicker, it separates electrodes 104 and 106 and their corresponding unlike charges, thus raising the electrical energy and voltage of the charge. Further, when electrodes 104 and 106 contract to a smaller area, like charges within each electrode compress, also raising the electrical energy and voltage of the charge. Thus, with different charges on electrodes 104 and 106, contraction from a shape such as that shown in FIG. 1B to one such as that shown in Figure 1A raises the electrical energy of the charge—which may be detected and measured by a circuit in electrical communication with the electrodes. That is, mechanical deflection is being turned into electrical energy and the transducer portion 100 is acting as a mechanical deflection sensor. Sensing performance of electroactive polymer is further described in copending U.S. Patent Application No. 09/619,848, which was previously incorporated by reference for all purposes. In one embodiment, a device may be configured such that sensing may be performed simultaneously with the actuation. In this case, a small amplitude high frequency signal may be superimposed on the driving signal. Circuitry may then measure the high frequency response of the polymer as an indication of the capacitance. Such techniques are well-known to those skilled in the art.

In a specific embodiment, an electroactive polymer transducer acts as a large capacitor. By measuring changes in capacitance, corresponding changes in polymer physical dimensions and force loading may be calculated. Thus, the transducer may be used to detect motion of a feature included in an animated device, e.g., an arm. In one embodiment, the same electroactive polymer transducer that provides mechanical output in an animated device also provides sensing capabilities. These transducers may then be made into “smart transducers” that intrinsically incorporate position, force, tactile sensing, etc. These smart transducers may simplify feedback control of mechanical output for an animated device, thus allowing for enhanced dexterity and controlled mechanical output.

In one embodiment, transducers of the present invention act as a haptic sensor for detecting touch. For example, transducer 432 of face 430 may be used to detect

whether the face 430 is in contact with an object. Sensing contact may be advantageous for toys that provide an interactive and automatic response with a user. Force sensors, electroactive polymer based or other, may also be used to detect touch applied to the toy.

5 In another embodiment, transducers of the present invention act as kinesthetic interfaces. Since the transducers operate through a simple drive mechanism rather than a complex transmission, position and force measurements from the transducer may give a direct measurement of the position and loading on a feature included in an animatronic device.

10 In another embodiment, the animatronic eye of FIGs. 3C-3D is used in an optical sensor. In this case, electrode 426 has an opacity that varies with deflection. A transparent or substantially translucent polymer 427 is attached to the opacity varying electrode and deflection of the polymer 427 is used to modulate opacity of the eye. In the case of an optical switch, the opacity varying transducer interrupts a
15 light source communicating with a light sensor. Thus, deflection of the transparent polymer 427 causes the opacity varying electrode to deflect and affect the light sensor (turn the switch on/off). In a specific embodiment, the opacity varying electrode includes carbon fibrils or carbon nanotubes that become less opaque as electrode area increases and the area fibril density decreases.

20

5.4 INTERACTIVE CAPABILITY

Animated devices of the present invention may also be interactive with their environment. Interactive abilities of the present invention refer to both automatic interaction and manual interaction.

25 In one embodiment, animated devices of the present invention include a processor. Combining the ability to design animated devices having customized motions, sensing abilities of electroactive polymer transducers and conventional sensors, and electrical communication with a processor, animated devices of the present invention may be programmed with automatic interactive capabilities.

In a specific embodiment, a stuffed toy comprises a processor that communicates independently with electrodes that actuate transducers in the toy. The toy may also comprise sensing capabilities that provide haptic, acoustic, visual, or kinesthetic information. The information is then provided to the processor, which is
5 programmed to make decisions based on the feedback. In more elaborate designs, the sensor and processor may combine to make decisions based on context of the quantity being sensed. In a specific embodiment, electroactive polymer force sensors provide temporal and magnitude force information that a processor differentiates in order to provide interactive responses. For example, when a child user yanks on a stuffed toy,
10 the processor receives the force information from the sensors and provides an acoustic signal to a transducer. The stuffed toy then interactively responds with an acoustic output of 'ouch' from the transducer.

In one embodiment, an animated device provides biomimetic responses to a person interacting with the device. As to term is used herein, a biomimetic response
15 refers to response of a device that copies or mimics nature. For example, the stuffed toy just described may provide a suitable empathetic response based on feedback from a child. Thus, the sensors may sense a particular state of the child playing with the stuffed toy and then respond accordingly, e.g., the sensors detect sadness in the child using voice recognition and the processor responds by actuating facial
20 transducers for the stuffed toy similar to mask 430 of FIG. 4C to produce an empathetic facial gesture. The biomimetic response may be selected to diffuse the state of the person, e.g., the sensors detect sadness in the child and the processor actuates electroactive polymer transducers in the device to provide a happy response including both happy facial gestures and an acoustic output. In this case, the stuffed
25 toy is designed with electroactive polymer transducers that provide all movements associated with the appropriate empathetic responses required for interaction between the toy and person. This may include reactive eye movements, body language, facial gestures, acoustic output, etc. In another embodiment, animated devices for use in a theme park may be designed with biomimetic responses to a user.

30 In another embodiment, an animated device of the present invention provides tactile interaction with its environment. For example, one or more haptic sensors may be arranged under the skin in various places of the animated device. Each of the

haptic sensors then detects touch for different body portion of the animated device. The same transducer may then be responsible for actuation in response to user interaction. For example, a haptic electroactive polymer sensor may be placed in the nose of the stuffed toy and the nose wiggles when touched (via actuation of the electroactive polymer). Alternatively, the stuffed toy may receive time varying force feedback from its environment and react accordingly. For example the stuffed toy previously discussed may be a teddy bear that reactively pushes back when its paw is pushed. In a more elaborate design, the magnitude of reactive push is proportional to the force magnitude pushing on the paw. In another embodiment, automatic toy interaction is designed not to stop an action based on sensor feedback. For example, a toy dinosaur with biting capabilities powered by electroactive polymer transducers uses force feedback from the transducers to decide when not to keep biting.

In another embodiment, an animated device has a set of responses based on a given input. For example, a toy dinosaur comprising a number of electroactive polymer transducers, a depressible button switch on its back, and a processor that responds to depression of the button, may have a series of programmed responses to depression of the button, e.g., locomotion and acoustic output. The depressible button may be an electroactive polymer transducer acting as a sensor or a simple conventional electrical switch in communication with the processor.

Interactive toys of the present invention need not include a processor. For the exemplary fighting men game mentioned above, an individual fighter in the game may include be designed with joint compliance that provides an automatic and appropriate response when hit by another fighter, e.g., the fighter falls down after being hit hard in the head by the other fighter. In this case, a user may provide manual control of the transducers in their corresponding motions for the toy fighter.

5.5. ADDITIONAL APPLICATIONS

As the present invention includes transducers that may be implemented in both the micro and macro scales, and with a wide variety of designs, the present invention finds use in a broad range of applications where animated motion is desired.

Provided below are some additional exemplary applications for electroactive polymer transducer animated devices.

Animated devices of the present invention are also well-suited for use in the entertainment industry. Exemplary applications include animated device use in
5 moving displays of theatre, theme parks, theme park rides, dark walks, scenery, and special effects for the film and television industries. Since downtime due to mechanical failure and repair is a nontrivial consideration for conventional animatronic devices in theme park rides, the simplicity and reliability electroactive polymers provide make them well-suited for this application. In many cases, fault
10 tolerance may be built into an electroactive polymer based animatronic device included in theme park ride by using several smaller transducers in parallel, thus increasing reliability of the device and minimizing downtime of the ride.

One of skill in the art will appreciate the wide use of animatronics in entertainment special effects work. Some exemplary animated devices found in the
15 entertainment industry suitable for use with electroactive polymer transducers include animatronic puppets, creatures and creature effects, sculptures, masks, special effects make-up, figures, prosthetics, props, scenic and set decorations, and character costumes. Exemplary creature effects include masked monsters, aliens, apes, dinosaurs, animatronic figures, etc. Special effects makeup include effects such as
20 latex masks and devices added to a person, animal or other device, e.g., to appear if skin is bulging by putting a prosthetic on their skin and actuating it.

The present invention is also suitable for sporting animated devices. Exemplary sporting animated devices include decoys such as animated ducks used for attracting game and electroactive polymer transducer powered fishing lures. The
25 decoys may also be used in animal and pest traps such as a flapping fly, crawling insect or wiggling worm or insect used in a pest trap, for example.

Animated devices of the present invention may also be used in medical training. This includes mannequins and training instruments that incorporate sensing and interactive capabilities. For example, a CPR training mannequin may include
30 force sensors to detect the degree of chest expansion provided by a CPR trainee. In addition, the CPR training mannequin may include customized motions of a feature

that provides interactive response based on CPR trainee performance, e.g., a diaphragm actuator that operates similar to actuator 130 of FIG. 2F and repeatedly actuates to simulate a pulse.

The present invention also finds use in novelty items that include animated motion. Exemplary novelty items suitable for use with present invention include
5 singing fish, dancing flowers, Halloween and Christmas novelty items such as dancing Santas, etc.

10

8. 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
15 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 as an electrode. It is therefore intended
that the scope of the invention should be determined with reference to the appended
claims.

What is claimed is:

1. An animated device comprising a feature capable of motion between a
5 first position and a second position, the animated device comprising a transducer
configured to provide at least a portion of the motion between the first position and
the second position for the feature, the transducer comprising an active area, which
includes at least two electrodes coupled to a portion of an electroactive polymer, the
portion capable of deflection in response to a change in electric field provided by the
10 at least two electrodes.

2. The device of claim 1 wherein elastic return of the electroactive
polymer provides at least a portion of the motion from the second position to the first
position.

15 3. The device of claim 1 wherein the electroactive polymer is pre-
strained.

4. The device of claim 1 wherein the electroactive polymer is a dielectric
elastomer.

5. The device of claim 1 wherein the electroactive polymer is molded.

20 6. The device of claim 5 wherein the electroactive polymer provides
structural support for the device.

7. The device of claim 1 wherein a mechanical property of the transducer
substantially simulates a mechanical property of a real muscle.

8. The device of claim 1 wherein the device is one of a toy, a puppet, and
25 an animatronic device.

9. The device of claim 8 further comprising a second transducer, the
second transducer comprising a second active area, which includes at least two

second active area electrodes coupled to a portion of a second electroactive polymer, the portion capable of deflection in response to a change in electric field provided by the at least two second active area electrodes

10. The device of claim 1 wherein the transducer is included in a linear
5 actuator.

11. The device of claim 1 wherein the device is included in one of an animated display, a set, a prop, and a moving display of an amusement park ride.

12. The device of claim 1 wherein the device includes a first member attached to the polymer which is also attached to the feature, wherein the feature
10 configured to rotate about the first member upon deflection of the polymer.

13. The device of claim 1 wherein the transducer further comprises a second active area, said second active area comprising at least two second active area electrodes and a second portion of the electroactive polymer coupled to the at least two second active area electrodes.

14. The device of claim 13 wherein the first active area and the second
15 active area are capable of independent actuation.

15. The device of claim 1 wherein the device is a distributed animated device.

16. The device of claim 15 wherein the distributed animated device
20 comprises an arm.

17. The device of claim 1 wherein the device includes remote control that controls deflection of the portion of an electroactive polymer.

18. The device of claim 1 wherein the device is one of a decoy or a fishing lure.

19. The device of claim 1 wherein the device is configured such that the
25 transducer is used in a sensor.

20. The device of claim 19 wherein the sensor provides one of haptic and force feedback.

21. The device of claim 1 wherein the device is configured such that the transducer is capable of producing sound.

5 22. The device of claim 1 wherein the device is backdrivable between the first position and the second position.

23. The device of claim 22 wherein backdriving is accomplished by overcoming the stiffness of the polymer during motion between the first position and the second position.

10 24. The device of claim 1 wherein the device is capable of surface based locomotion.

25. The device of claim 24 wherein the first position and the second position are included in legged locomotive positions of a toy.

15 26. The device of claim 1 wherein motion between the first position and the second position for the feature has human likeness.

27. An animated face comprising a facial feature capable of motion between a first position and a second position, the animated face comprising a transducer configured to provide at least a portion of the motion between the first position and the second position for the facial feature, the transducer comprising an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer, the portion capable of deflection in response to a change in electric field provided by the at least two electrodes.

20

25 28. The animated face of claim 27 wherein the electroactive polymer is molded to the shape of the face.

29. The animated face of claim 28 further comprising an outer skin attached to an outer surface of the polymer.

30. The animated face of claim 27 wherein the facial feature is a mouth and the first position and the second position correspond to positions of the mouth.

5 31. The animated face of claim 27 wherein the facial feature is an eyebrow and the first position and the second position correspond to positions of the eyebrow.

32. The animated face of claim 27 wherein the facial feature is a pupil and actuation of the polymer corresponds to dilation of the pupil.

10 33. The animated face of claim 27 wherein the transducer further comprises a second active area, said second active area comprising at least two second active area electrodes and a second portion of the electroactive polymer coupled to the at least two second active area electrodes.

15 34. The animated face of claim 33 wherein said first and second active areas are actuated one of independently or together to provide motion for one or more parts of said face.

20 35. An animated toy having a feature capable of motion between a first position and a second position, the animated toy comprising a transducer configured to provide at least a portion of the motion between the first position and the second position for the feature, the transducer comprising an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer, the portion capable of deflection in response to a change in electric field provided by the at least two electrodes.

25 36. The toy of claim 35 wherein the first position and the second position are included in facial positions of the toy.

37. The toy of claim 35 wherein the toy is capable of surface based locomotion.

38. The toy of claim 35 wherein the first position and the second position are included in legged locomotive positions of the toy.
39. The toy of claim 35 wherein the electroactive polymer is a dielectric elastomer.
- 5 40. The toy of claim 35 wherein the toy includes remote control that controls deflection of the portion of the electroactive polymer.
41. The toy of claim 35 wherein the toy comprises a sensor.
42. The toy of claim 41 wherein the toy is configured such that the transducer is used in the sensor.
- 10 43. The toy of claim 42 wherein the sensor provides one of haptic and force feedback.
44. The toy of claim 35 wherein the toy is configured such that the transducer is capable of producing sound.
45. The toy of claim 35 wherein the toy is backdrivable between the first
15 position and the second position.
46. The toy of claim 45 wherein backdriving is accomplished by overcoming the stiffness of the polymer during motion between the first position and the second position.
47. The toy of claim 35 wherein the toy comprises a distributed transducer
20 scheme.
48. The toy of claim 35 wherein the toy comprises a body including a torso having a pair of arms extending therefrom, a head, a pair of legs extending downwardly therefrom, a neck portion supporting the head.
- 25 49. An animated skin comprising a feature capable of motion between a first position and a second position, the animated skin comprising a transducer

configured to provide at least a portion of the motion between the first position and the second position for the feature, the transducer comprising an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer, the portion capable of deflection in response to a change in electric field provided by the
5 at least two electrodes.

50. The animated skin of claim 49 further comprising a convex surface attached to a portion of the skin.

51. The animated skin of claim 49 further comprising an outer skin
10 attached to an outer surface of the polymer.

52. The animated skin of claim 49 wherein the transducer is included in a diaphragm actuator.

53. The animated skin of claim 49 wherein the device is configured such that the transducer is capable of producing sound.
15

54. An animated device having a feature capable of motion between a first position and a second position, the animated device comprising a transducer configured to provide at least a portion of the motion between the first position and the second position for the feature, the transducer comprising an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer, the portion capable of deflection in response to a change in electric field provided by the
20 at least two electrodes; the animated device also comprising a sensor.

55. The device of claim 54 wherein the sensor provides one of haptic information, kinesthetic information, visual information, and acoustic information.
25

56. The device of claim 54 wherein the sensor comprises a second electroactive polymer.

57. The device of claim 54 wherein the sensor comprises the transducer.

58. The device of claim 54 wherein the device is configured such that sensing may be performed simultaneously with the actuation.

59. The device of claim 54 further comprising a processor and electrical communication with the at least two electrodes.

5 60. The device of claim 59 wherein the processor is in electrical communication with the sensor.

61. The device of claim 60 wherein the device is capable of interaction with its environment.

62. The device of claim 61 wherein the device provides biomimetic
10 responses to a user.

63. The device of claim 54 wherein the device is one of a toy and an animatronic device.

15 64. An animated device having a feature capable of motion between a first position and a second position, the animated device comprising a transducer configured to provide at least a portion of the motion between the first position and the second position for the feature, the transducer comprising an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer, the
20 portion capable of deflection in response to a change in electric field provided by the at least two electrodes; the animated device also capable of acoustic emission.

65. The device of claim 64 wherein the transducer is configured to
25 produce sound.

66. The device of claim 64 further comprising a second transducer, said second transducer comprising at least two second transducer electrodes coupled to a portion of a second electroactive polymer, the portion of the second electroactive
30 polymer capable of deflection in response to a change in electric field provided by the

at least two second transducer electrodes, and wherein the second transducer is configured to produce sound.

67. The device of claim 64 wherein the device comprises a sensor.

68. The device of claim 64 wherein the device is configured such that the
5 transducer is used in the sensor.

69. The device of claim 67 wherein the sensor detects acoustic information.

70. An animated device capable of surface based locomotion and having a feature capable of motion between a first position and a second position, the animated
10 device comprising a transducer configured to provide at least a portion of the motion between the first position and the second position for the feature, the transducer comprising an active area, which includes at least two electrodes coupled to a portion of an electroactive polymer, the portion capable of deflection in response to a change in electric field provided by the at least two electrodes; wherein the device is
15 configured such that motion between the first position and the second position for the feature provides at least a portion of the surface based locomotion.

71. The device of claim 70 wherein the surface locomotion is wheeled locomotion and the feature is a wheel driven by the transducer.

72. The device of claim 70 wherein the surface locomotion is legged
20 locomotion and the feature is a leg.

73. The device of claim 72 wherein the device is a toy.

74. The device of claim 70 wherein the device includes remote control that controls deflection of the portion of an electroactive polymer.

75. A doll comprising:

25 a body comprising a torso having a pair of arms extending therefrom, a head, a pair of legs extending downwardly therefrom, a neck portion supporting the head; and a transducer configured to move a feature on the doll, the transducer comprising an active area, which includes at least two electrodes coupled to a portion of an

electroactive polymer, the portion capable of deflection in response to a change in electric field provided by the at least two electrodes.

76. The doll of claim 75 wherein the transducer is configured to move one
5 of said head, said neck, said pair of legs, and pair of arms relative to the torso.

77. The doll of claim 75 wherein the first position and the second position
are included in included in facial positions of the doll.

78. The doll of claim 75 wherein the transducer is configured to move the
feature in a manner that simulates one of liquid drinking action, swallowing action,
10 dancing, talking, smiling, and simulated skating action.

79. An animated device having likeness of a human and a feature capable
of motion between a first position and a second position, the animated device
comprising a transducer configured to provide at least a portion of the motion
15 between the first position and the second position for the feature, the transducer
comprising an active area, which includes at least two electrodes coupled to a portion
of an electroactive polymer, the portion capable of deflection in response to a change
in electric field provided by the at least two electrodes, wherein the feature has a
human likeness.

20

80. The device of claim 79 wherein the motion between the first position
and the second position for the feature has a human likeness.

81. The device of claim 79 wherein the device resembles a non-living
object and the transducer provides motion for a feature having a human likeness.

25 82. The device of claim 79 wherein the electroactive polymer is a
dielectric elastomer.

83. The device of claim 79 wherein the device is a distributed animated device.

84. The device of claim 83 wherein the distributed animated device comprises an arm.

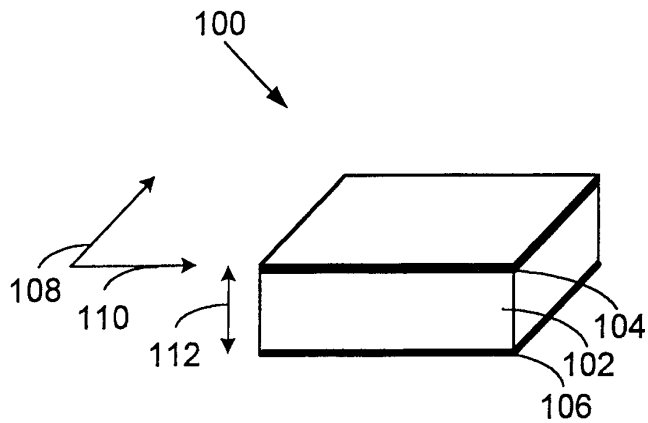


FIG. 1A

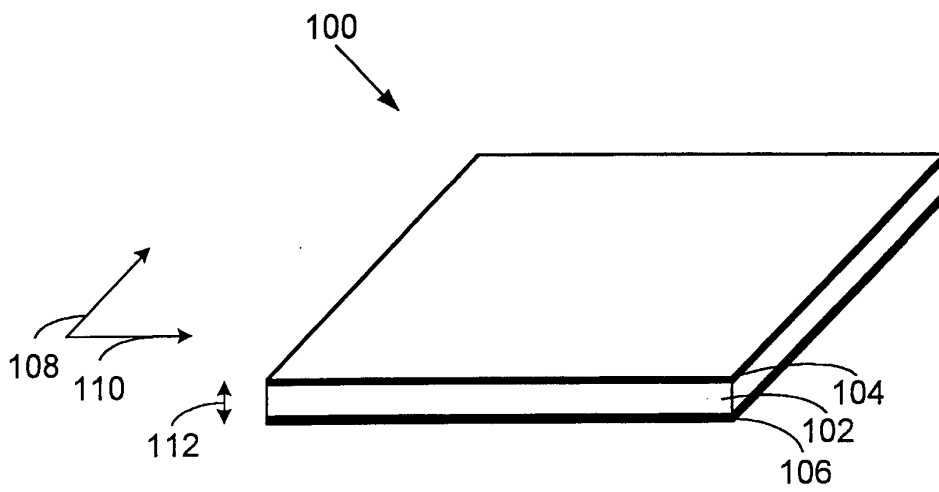


FIG. 1B

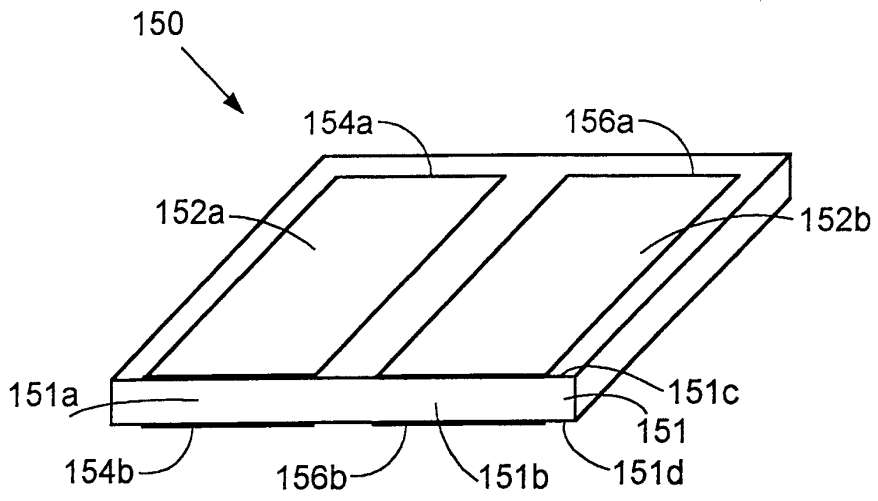


FIG. 1C

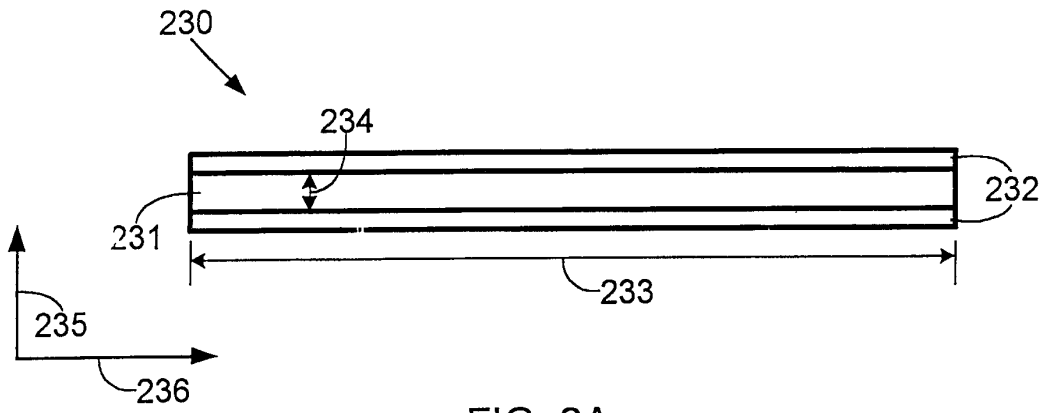


FIG. 2A

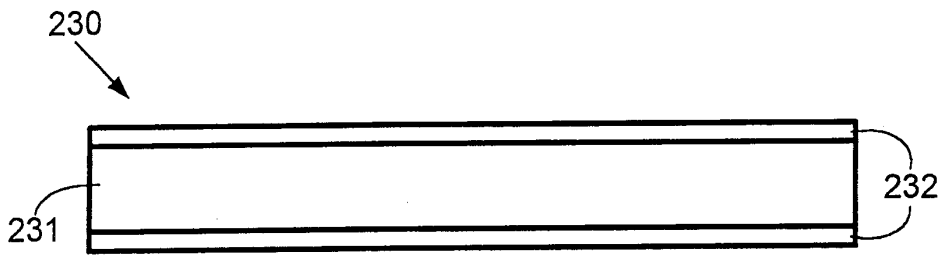


FIG. 2B

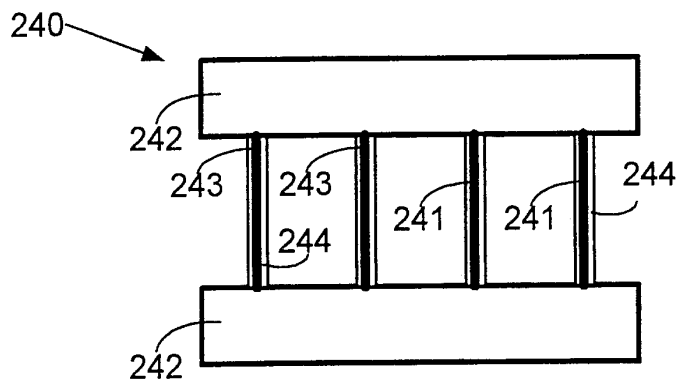


FIG. 2C

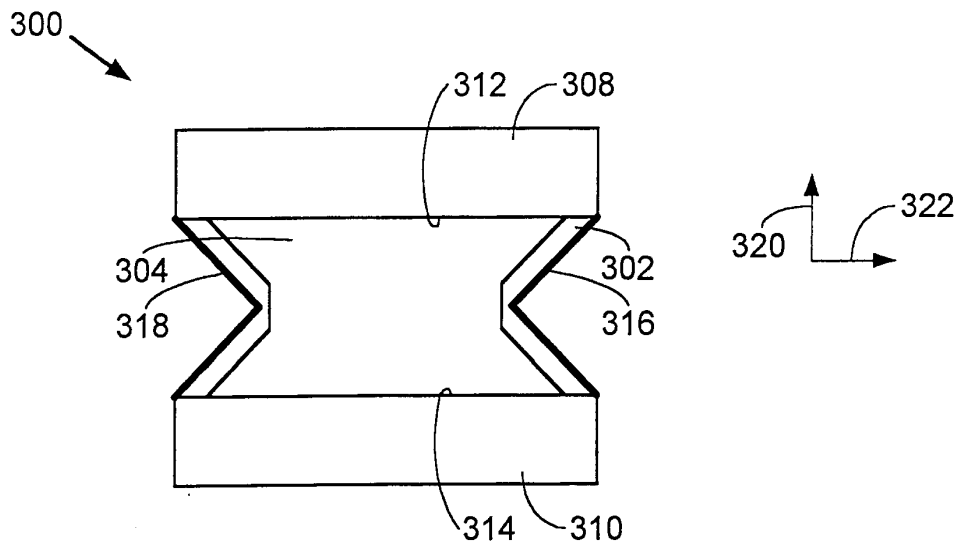


FIG. 2D

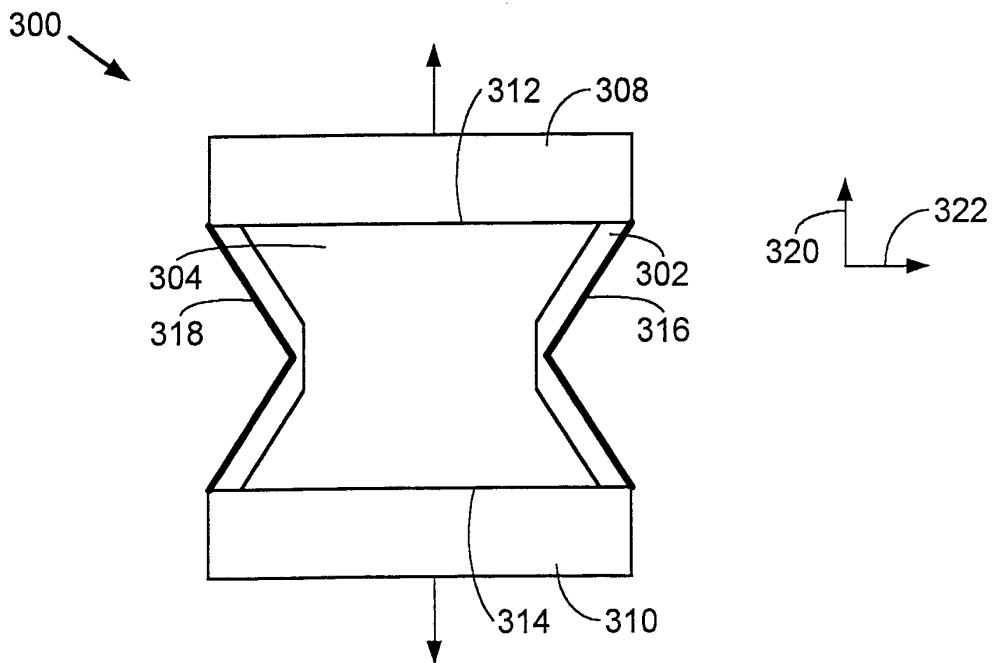


FIG. 2E

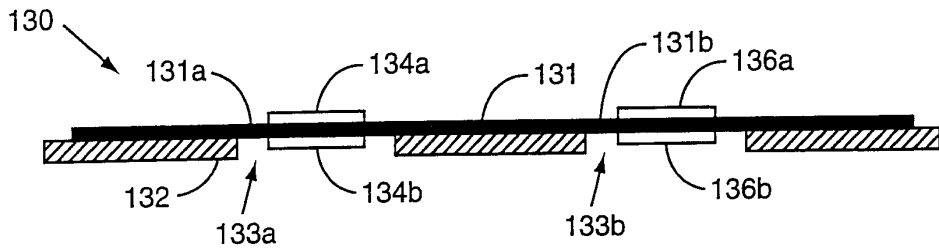


FIG. 2F

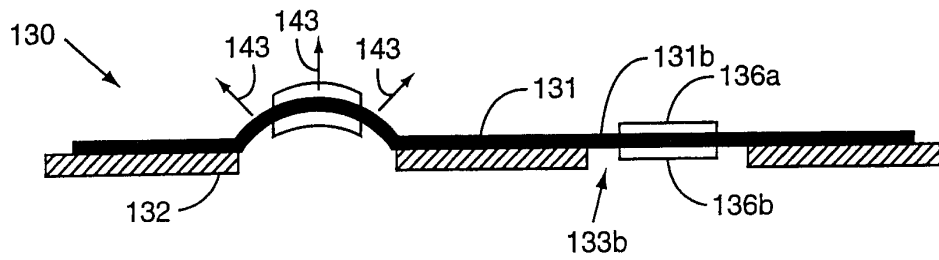


FIG. 2G

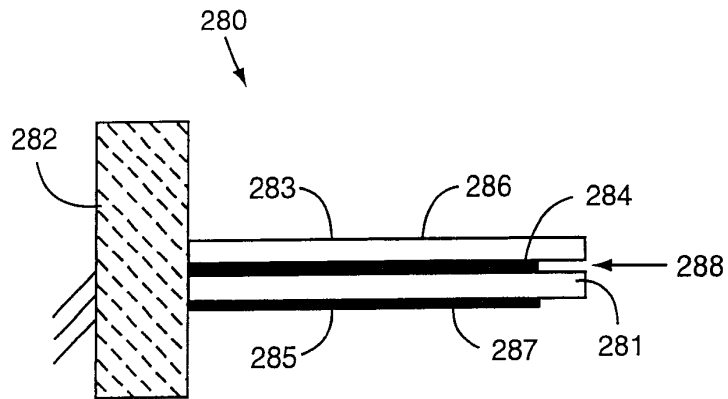


FIG. 2H

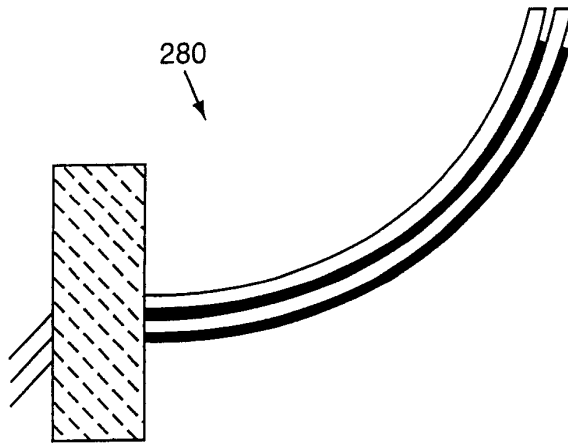


FIG. 2I

400 ↘

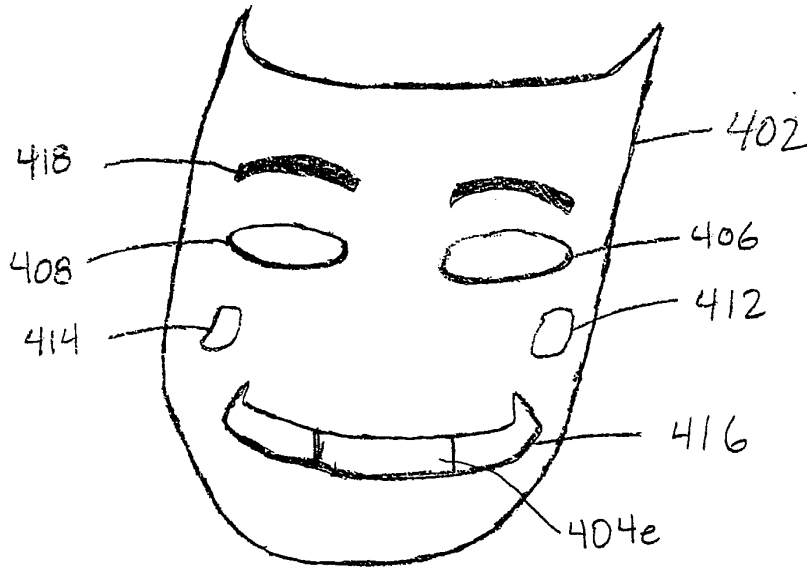


FIG. 3A

400 ↘

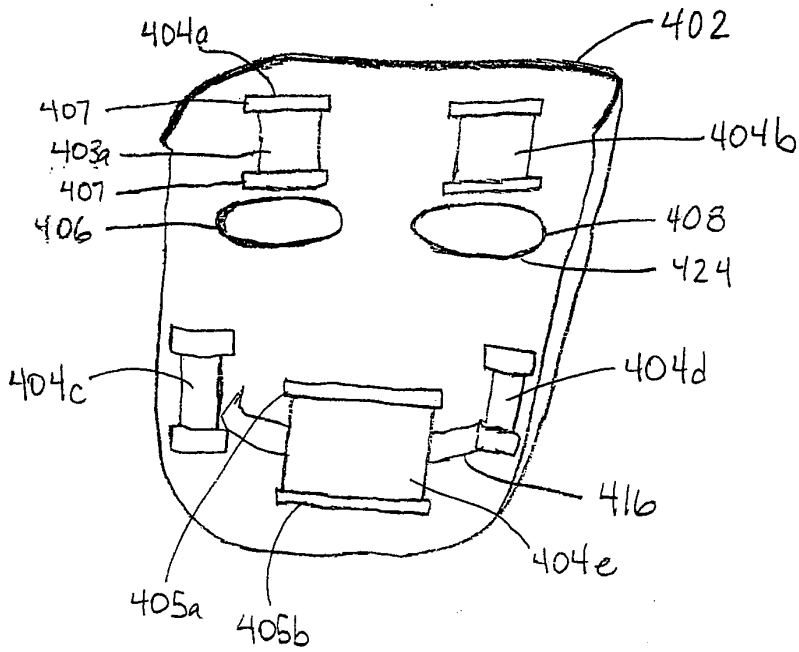


FIG. 3B

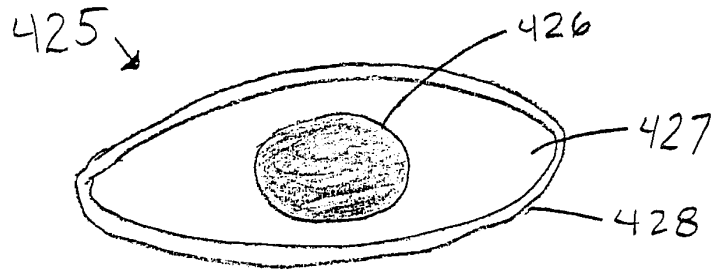


FIG. 3C

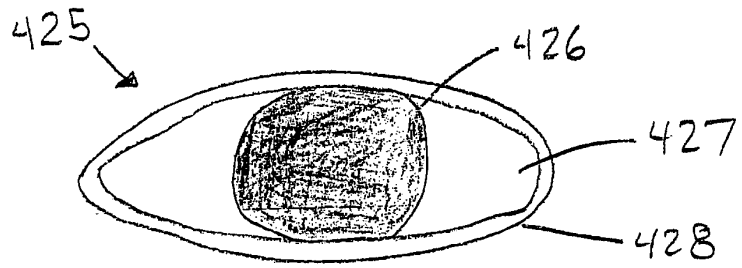


FIG. 3D

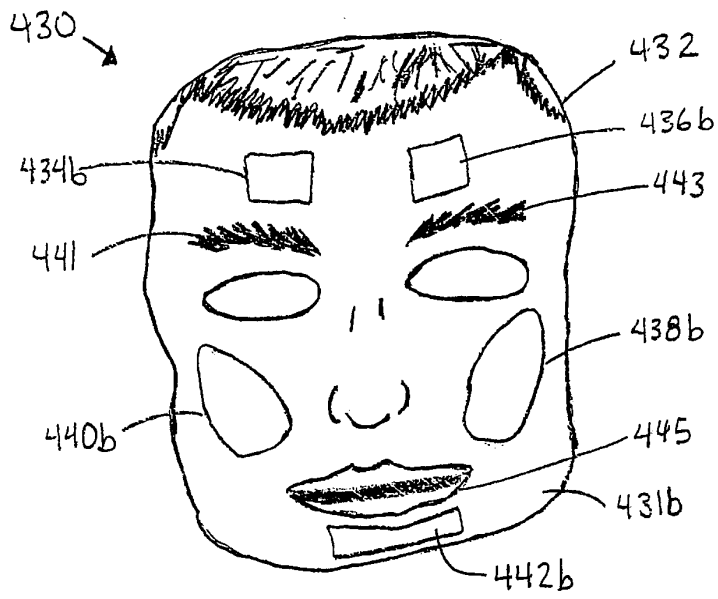


FIG. 3E

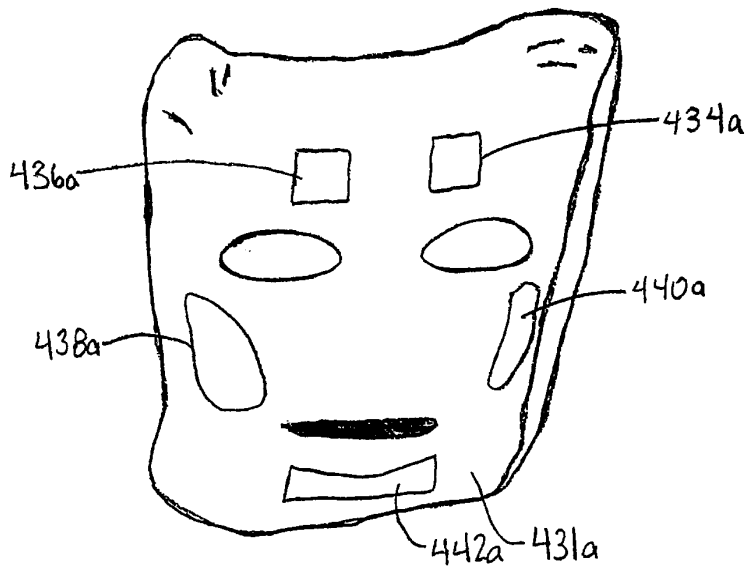


FIG. 3F

450 ↘



FIG. 3G

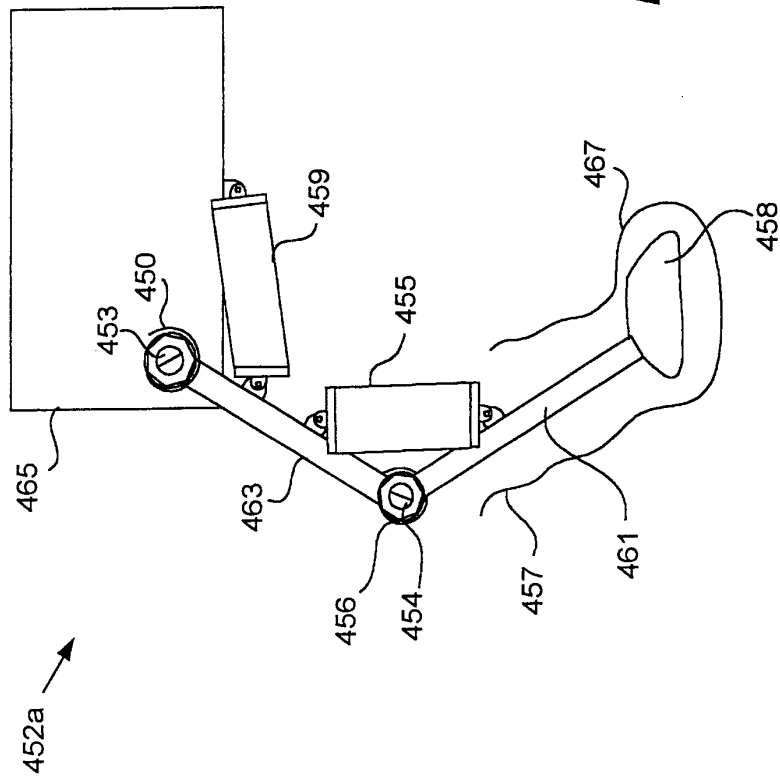


FIG. 3H

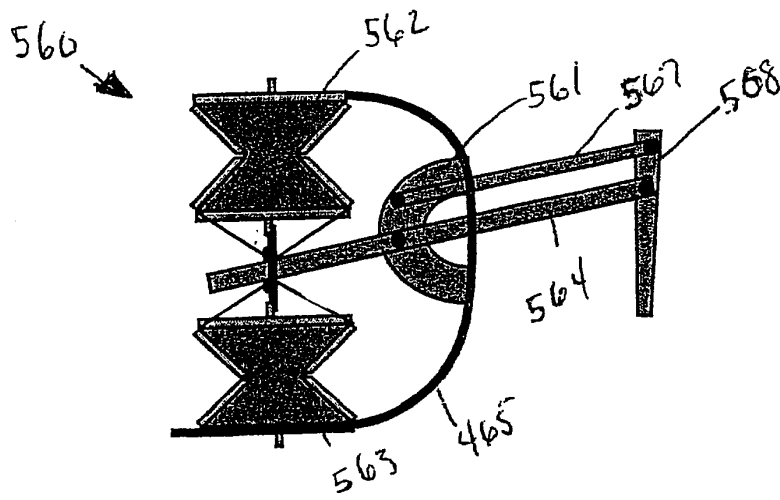


FIG. 3I

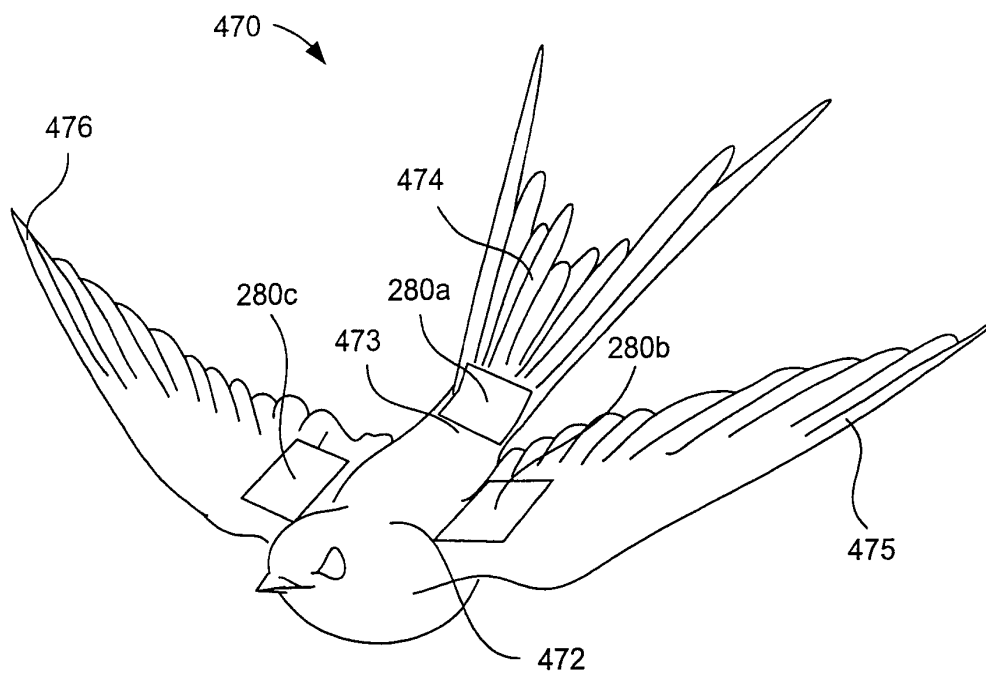


FIG. 3J

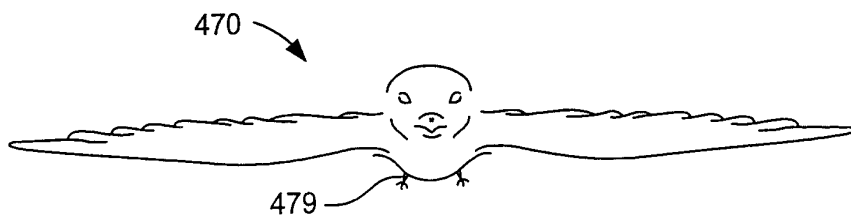


FIG. 3K

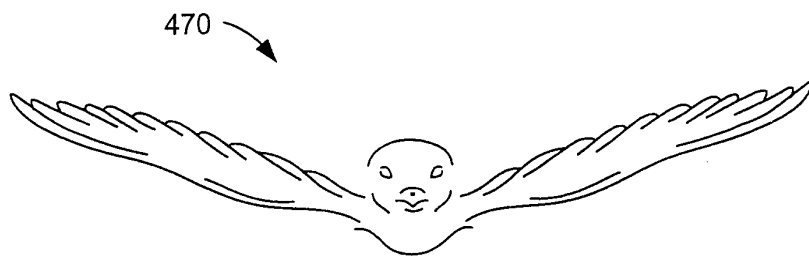


FIG. 3L

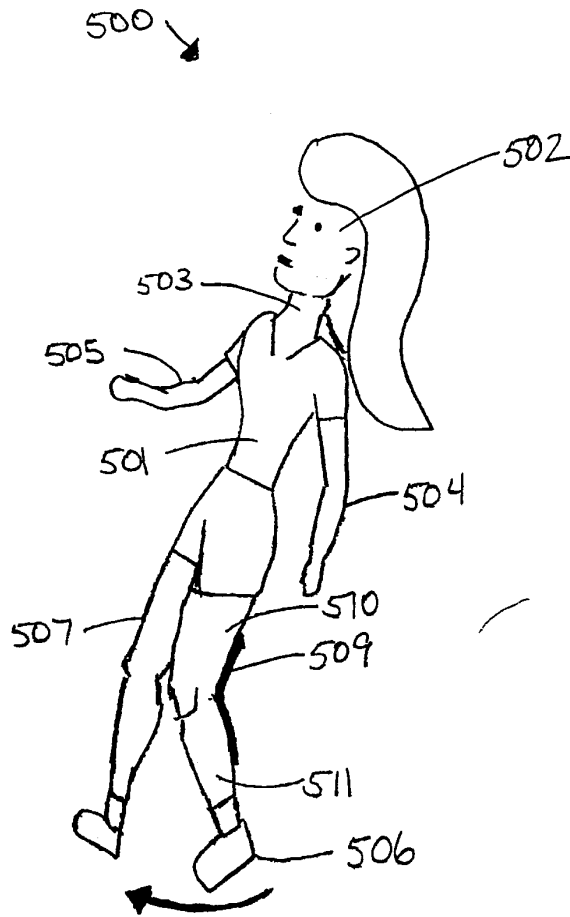


FIG. 3M