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(54) METHOD AND APPARATUS FOR SENSING THE FORCE WITH WHICH A BUTTON IS PRESSED

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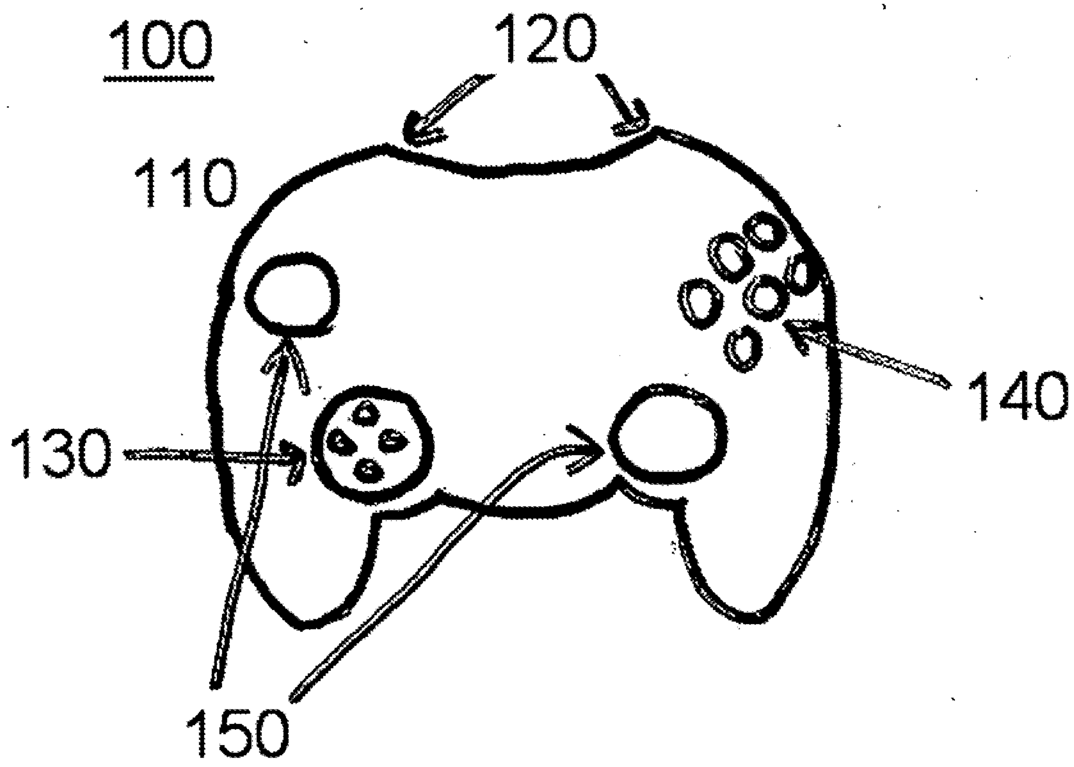
(57) ABSTRACT

An example method includes measuring a capacitance of an actuator and a conductive element when, responsive to a force applied to the actuator, the actuator is coupled to a reference voltage and deformed such that surface area of the actuator proximate to the conductive element increases. The example method includes determining the force applied to the actuator based on the measured capacitance.



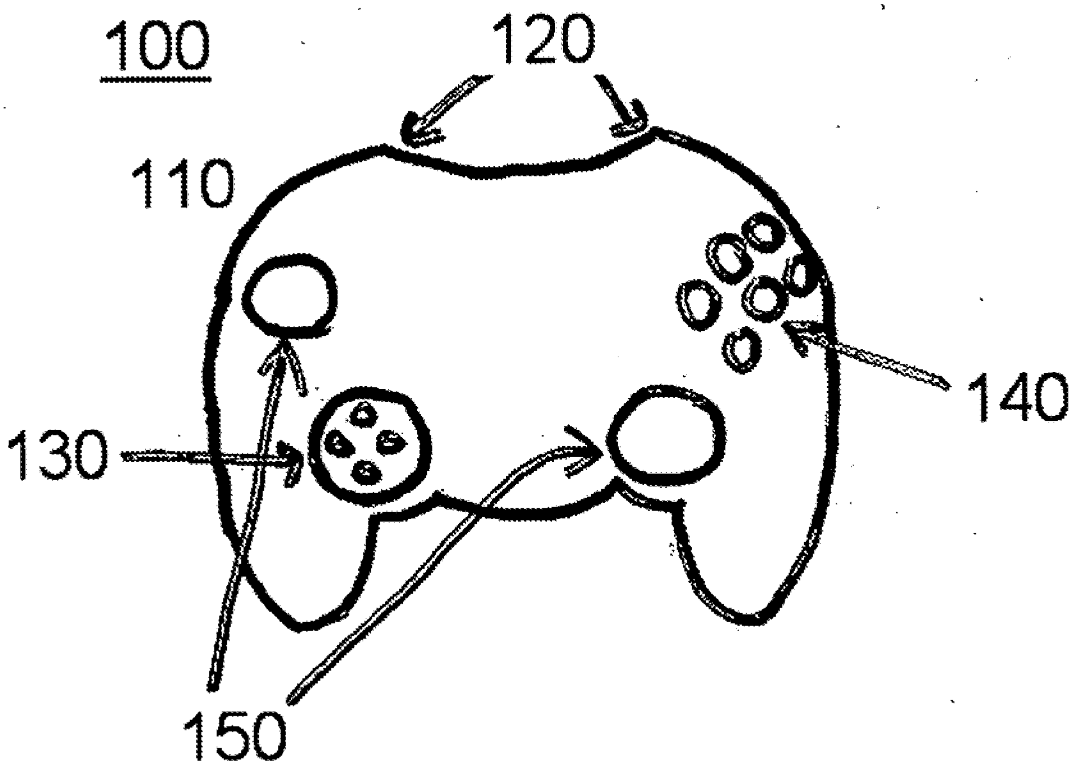


Figure 1.

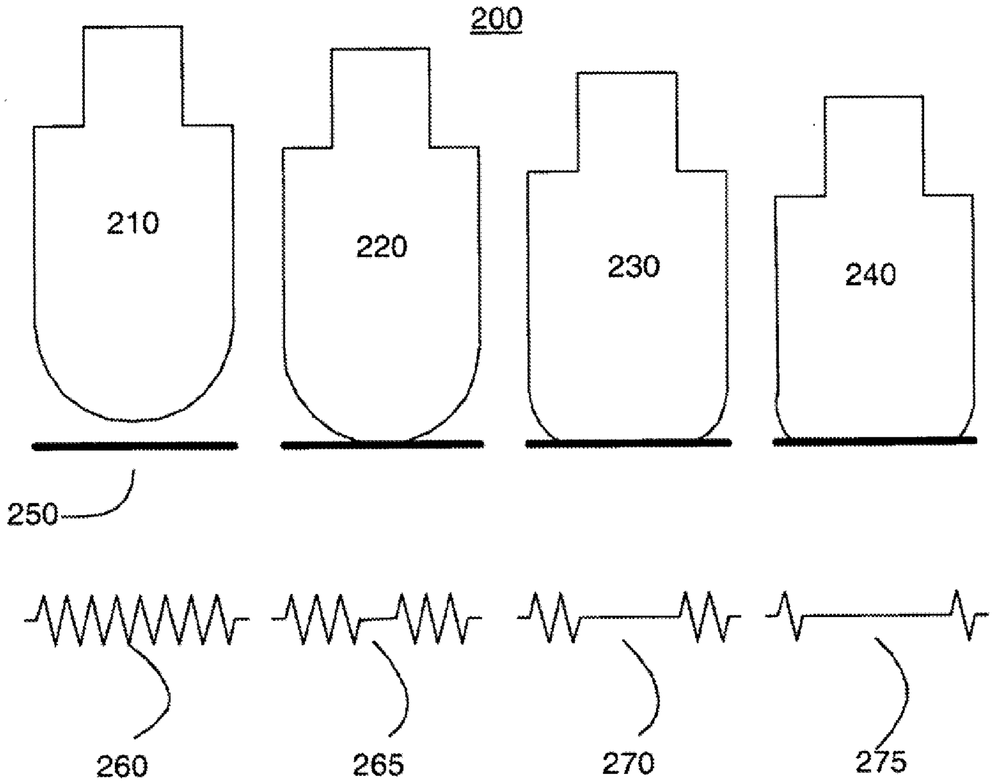


Figure 2.

FIG. 3

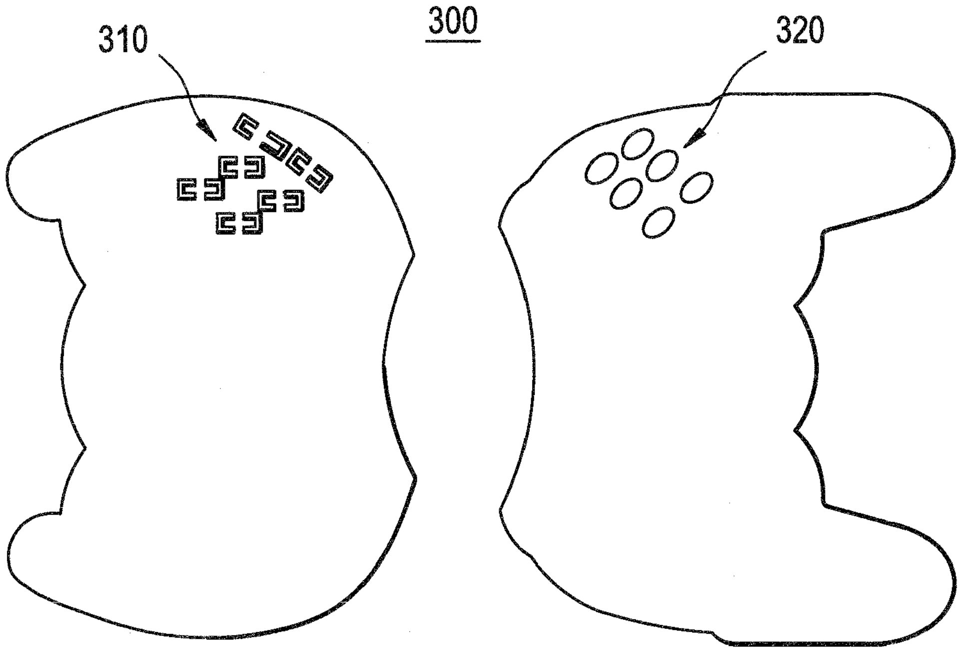
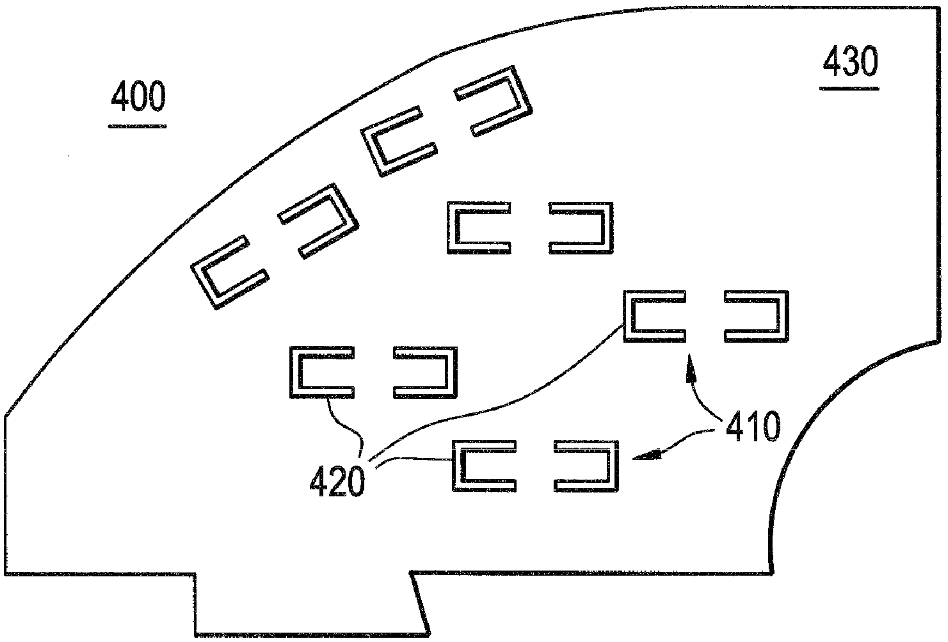


FIG. 4



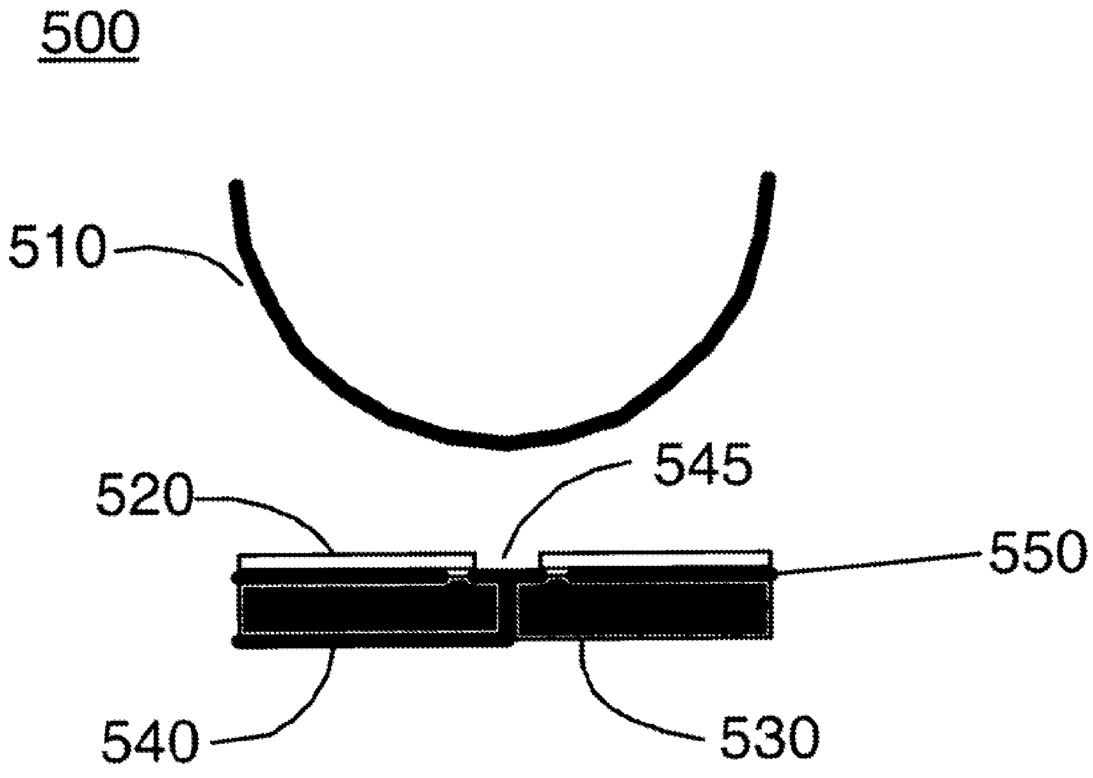


Figure 5.

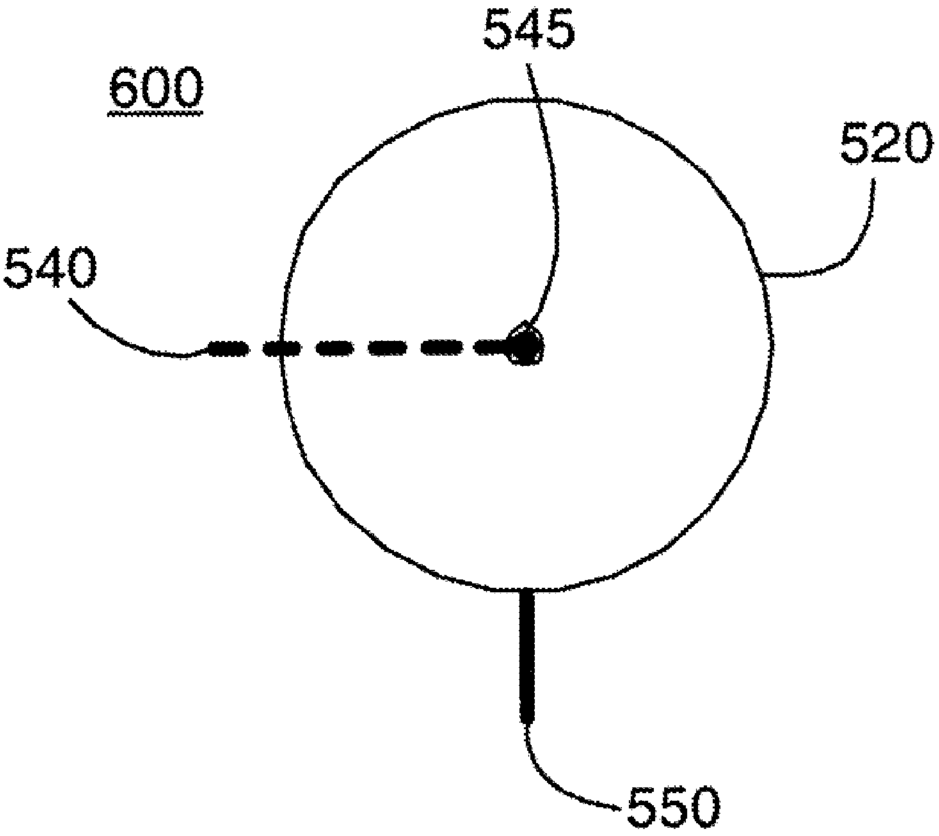


Figure 6.

FIG. 7

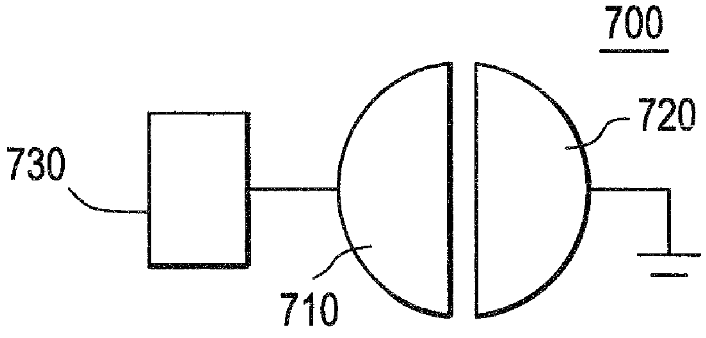


FIG. 8

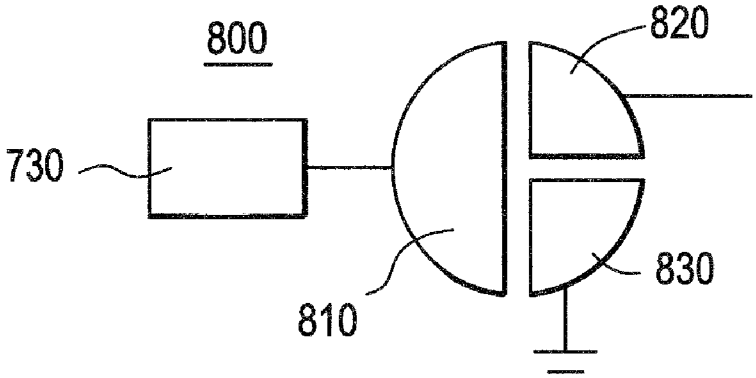
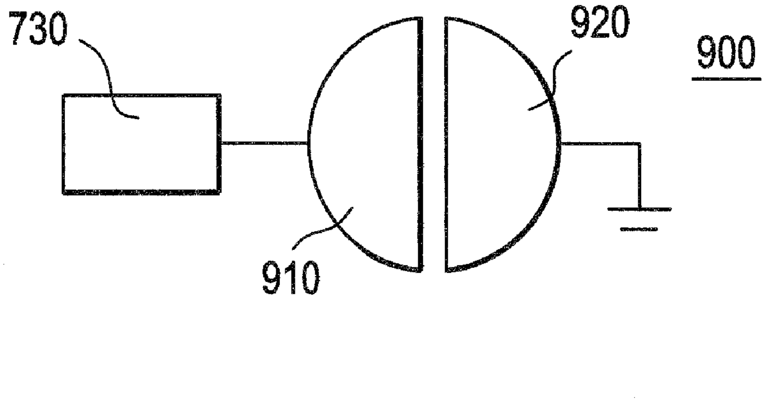


FIG. 9



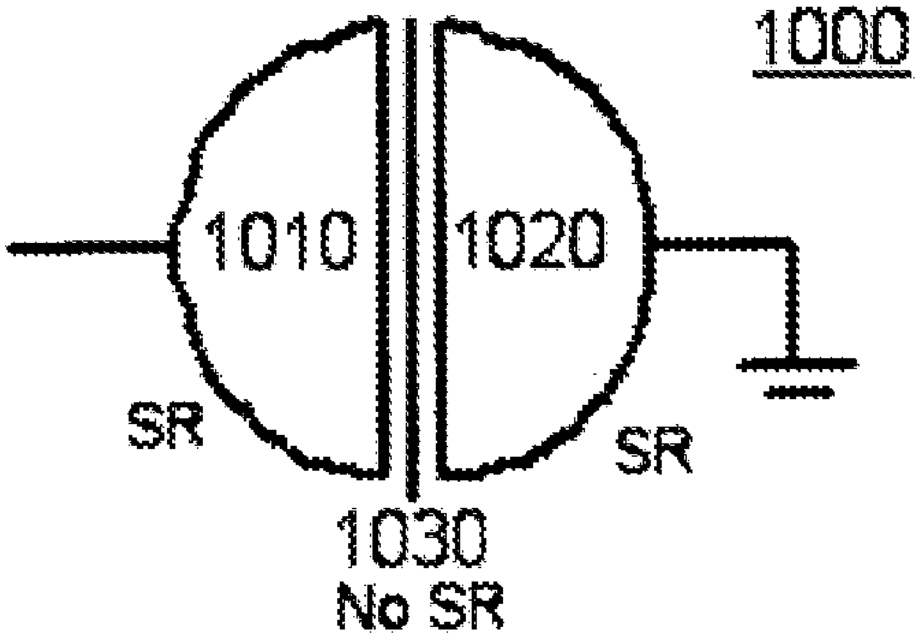


Figure 10.

METHOD AND APPARATUS FOR SENSING THE FORCE WITH WHICH A BUTTON IS PRESSED

TECHNICAL FIELD

[0001] The present invention relates generally to electronic circuits and in particular to circuits for sensing force.

BACKGROUND

[0002] Force-sensing buttons have found recent widespread use in human interface devices such as gamepads for the entertainment consoles like the Sony PlayStation™ and Microsoft Xbox™. A conventional gamepad **100** is shown in FIG. **1**. The conventional gamepad **100** comprises a housing **110**, having four force-sensing triggers **120**, a D-pad **130** with four force sensing buttons controlled by a left hand, four force sensing buttons **140** controlled by a right hand, and two thumbsticks **150** controlled by thumbs. The force sensing buttons comprise electronic force sensing actuators (in which the force applied to a button is sensed, rather than the binary state of a button) to provide variable force inputs to the console. In this conventional gamepad, there are twelve force sensing buttons/actuators. Typically each force sensing button/actuator output is translated in a six or eight bit value representing the force applied.

[0003] One conventional implementation for a force sensing actuator is the use of a force sensing resistor, such as those sold by Interlink Electronics (cited in information disclosure statement). However the force sensing resistor solution is too expensive for many applications where cost is an important factor. Many purchasers of gamepads and other consumer products are very price sensitive, so having a low manufacturing cost is important.

[0004] Another lower cost conventional implementation (which has been adopted by many gamepad manufacturers) is to use a resistive track printed on a printed circuit board (PCB). Printed circuit boards typically comprise a substrate, with one or more layers of copper traces on the surface or sandwiched between layers of substrate. To prevent corrosion and to prevent short circuits, the copper traces are coated with a thin film of "solder resist" except at the locations of pads or holes where components are to be soldered to the copper traces. In some cases, the copper traces may be gold plated.

[0005] In some cases, PCBs also contain resistive carbon traces printed on one or both sides of the PCB. The resistivity of such traces may vary between a few ohms/square and several kilo ohms/square. Such carbon traces may be used for a variety of purposes, including preventing corrosion of exposed copper contacts and to implement a variable resistance in combination with an external actuator or wiper.

[0006] The cost of a PCB is determined primarily by its area, the type of substrate material used, the number and size of holes in the PCB, and the number of layers of copper traces. The minimum width of the traces, and the minimum distance between traces also may significantly affect PCB cost, but the number of traces, or the percentage of the area of the PCB that is covered in copper are not significant factors affecting the cost of a PCB.

[0007] FIG. 2 shows a conventional actuator button **200** such as one used in a gamepad or other control device. The button has a carbon-impregnated domed rubber actuator, which makes contact with a resistive carbon PCB track. As the button is pressed harder, the rubber dome deforms, progressively shorting out more of the printed carbon PCB track, reducing the end-to-end resistance of the track, as shown in FIG. **2**.

[0008] When the button is in the 'rest' position **210**, it is not in contact with a carbon track **250**, and resistive value of the track is shown as the resistor representation **260**. When the button is gently pressed it goes to position **220**, where the tip of the dome contacts the carbon track **250**, and shorts across a small portion of the track **250**. This is visible as the 'shorted out' portion of the resistor representation **265**. When the button is pressed more firmly as shown in position **230**, the tip of the dome deforms to become flatter and shorts out a larger portion of the track **250**. This is visible as the wider 'shorted out' portion of the resistor representation **270**. Finally, if the button is pressed hard as shown in position **240**, the tip of the dome deforms to become quite flat and shorts out a much wider portion of the track **250**, such that almost the entire track **250** is shorted out. This is visible as the widest 'shorted out' portion of the resistor representation **275**.

[0009] The arrows in the drawing show the portion of the track which is not shorted out, and which is therefore resistive. The area between the arrows shows the area of the track which is shorted out. It can therefore be seen that as the rubber button is pressed harder, more of the track is shorted out, and the total resistance between the 2 ends of the track is reduced. The resistive track usually has a total resistance of a few kilo ohms, while the resistance of the conductive coating on the bottom of the rubber button is typically a few ohms at most. The resistance may be measured by placing a second resistor (for example 10K Ohms) in series with it to form a potentiometer, and measuring the output voltage from the potentiometer using an analog to digital converter (ADC).

[0010] This conventional actuator button and resistive track of FIG. **2** is somewhat less accurate than the force sensing resistor (FSR) approach, and has lower linearity. The main reason for the lower accuracy and non-linearity of the conventional actuator button and resistive track is the difficulty in printing a resistive track with a consistent resistivity along its length, and consistent resistivity from printed track to printed track. It is difficult to accurately control the thickness of the printed trace in a mass manufacturing process. However, absolute accuracy and linearity may not be important in many applications, and with calibration it is possible to give reasonably consistent results. Firmware may be used to calibrate for the non-linearity and also to calibrate for the changes in resistance as the rubber dome wears out with use. However, while the conventional actuator button and resistive track solution is less expensive than a force sensing resitor, it still costs several cents for each printed resistive trace on the PCB, and such costs can be significant in a consumer product with many force-sensing buttons (for example twelve buttons in the example of FIG. **1**).

[0011] FIG. **3** shows a disassembled conventional gamepad **300**, with resistive carbon traces **310**, and conductive rubber dome actuators **320**.

[0012] FIG. **4** shows a printed circuit board layout **400** of the conventional gamepad. The layout **400** shows resistive carbon printed traces **410**, PCB traces **420**, and solder resist (in this case blue, generally green in color) **430**.

[0013] It would be desirable to have a less expensive force sensing button. A preferred force sensing button would be "free" (apart from the cost of the actuator itself) and provide linear sensing of force, with absolute accuracy that was consistent after calibration (low drift).

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** illustrates a conventional gamepad device.

[0015] FIG. **2** illustrates a conventional actuator button.

[0016] FIG. **3** illustrates a disassembled conventional gamepad.

[0017] FIG. **4** illustrates a printed circuit board layout of the conventional gamepad layout.

[0018] FIG. **5** illustrates a side view of an improved force sensing actuator.

[0019] FIG. **6** illustrates a plan view of an improved force sensing actuator

[0020] FIG. **7** illustrates an alternative embodiment of the improved force sensing actuator.

[0021] FIG. **8** illustrates another embodiment of the improved force sensing actuator.

[0022] FIG. **9** illustrates another alternative embodiment of the improved force sensing actuator

[0023] FIG. **10** illustrates another alternative embodiment of the improved force sensing actuator

DETAILED DESCRIPTION

[0024] Described is a solution for a force sensing actuation that uses the electrical properties of a printed circuit board, together with a conductive-tip actuator as to make a force-sensing button at extremely low cost.

[0025] FIG. **5** shows a side view **500** of the improved solution. The improved solution comprises a rubber actuator dome **510** which has a conductive layer (in one embodiment carbon) on the surface. In another embodiment, the entire actuator dome could be formed of conductive flexible material, or be impregnated with conductive material. The rubber actuator dome **510** is positioned above a PCB substrate **530**. A conductive layer **550** is formed on the PCB substrate **530**, and an insulating solder resist layer **520** is formed over the conductive layer **550**. In one embodiment, the conductive layer **550** is a PCB trace comprising copper or an alloy thereof. A trace **540** is formed on a lower layer or on the opposite side of the PCB from the conductive layer **550** and the solder resist **520**. The trace **540** is electrically isolated (i.e. not shorted to) from the conductive layer **550**, the trace **540** forms a contact **545** on the PCB on the same side as the solder resist **520**. The contact **545** is not fully covered by solder resist **520**, such that any conducting material pressed down onto the top surface of the substrate will make electrical contact with contact **545**. In another embodiment the contact **545** is exposed (i.e. there is no solder resist over it).

[0026] FIG. **6** shows a plan view **600** of the arrangement of FIG. **5**. Plan view **600** shows the PCB trace **550** (in one embodiment in a circular shape, but could have any shape). Located between the edges of the PCB trace is the contact **545**. In one embodiment this may be located approximately in the center of the PCB trace **550**. Trace **540** is shown as a dotted line, this trace will be electrically connected to the rubber actuator dome **510** (which is not shown in the plan view) when the dome is pressed into contact with the substrate. Trace **560** is the trace from the lower electrode which is coupled to conductive PCB trace **550**.

[0027] The actuator **510** is formed of, impregnated with or coated with a conductive material with a low resistivity, for example carbon. The rubber actuator dome may be the same type as used in conventional solutions. Solder resist is commonly used to coat the copper traces of a PCB to protect it from short circuits and oxidation and is of relatively uniform thickness and reasonably constant relative permitivity, with a value of approximately 4 in one example.

[0028] The value of the capacitance between two parallel plates is calculated as the permitivity of the material between the plates (the dielectric) multiplied by the overlapping area of the two plates, divided by the distance between the plates. Permitivity is commonly specified as two parts the permitivity of free space (epsilon-0 or E_0) and the relative permitivity of a particular material (gas, liquid, solid) known as epsilon-r or E_r. Thus, the permitivity (epsilon) is E_0*E_r.

[0029] A capacitor may be formed by the combination of a copper trace **550** (which acts as a lower plate), the solder resist **520** (which acts as a dielectric) and the conductive (e.g. carbon-printed) rubber actuator dome (which acts as an upper plate). As the actuator **510** is pressed down onto the PCB it will make contact with trace **540** through contact **545**; as the actuator is pressed down with greater force, it will deform and a greater area of the conductive button will come into close proximity with the lower plate **550**, thus increasing the capacitance between plate **550** and trace **540**. A circuit on the board can be used to measure this capacitance. The output to be measured is a frequency that varies with capacitance. One example of such a circuit used to measure capacitance is a relaxation oscillator; this and other circuits for accurately measuring or detecting small changes in capacitance will be familiar to one skilled in the art. A processing element may read the output of this circuit and thus infer the force with which the button is being pressed.

[0030] The shape of the conductive trace **550** or the solder resist **520** can be varied while preserving the function of the invention. In order to maximize the capacitance between the actuator **510** and the trace **550**, the trace **550** should generally cover the full area of contact of the actuator with the substrate when pressed with maximum force. In various configurations, the shape could be circle, square, rectangle, triangle, or any combination of these or other shapes. The shape could have 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 or more sides, depending on how PCB layout software implements the conductive trace. PCB design/layout software may approximate a circular shape with a many sided shape, as true curves may be difficult to implement in PCB layout software. The conductive trace **550** may completely surround the contact **545**, or may partially surround (such as a horseshoe shape) the contact **545**. The conductive trace **550** may also be formed as a plurality of pieces (such as a pie chart shape) surrounding or partially surrounding the contact **545**. The contact **545** may be located somewhere inside the limits of trace **520**; generally the contact **545** should be located at or close to the point on the substrate where the actuator first touches the PCB, i.e. where the actuator touches when pressed with least force.

[0031] The improved solution operates in the following manner. In a first step when the actuator **510** is first touched by a user, it touches the sensor contact **545** which connects the actuator dome **510** to trace **540**. In one example, trace **540** may be connected to electrical ground, such that dome **510** becomes grounded when it touches contact **545**. This creates a small capacitance between the trace **550** and a ground voltage coupled to trace **540** and contact **545**. In a second step when the actuator is pressed more firmly it deforms and approaches a wider surface of the trace **550** causing the capacitance between trace **550** and electrical ground to increase. In a third step, a circuit measures the capacitance. In a fourth step a microcontroller samples the circuit output and determines the capacitance value. In a fifth step, a digital representation of that capacitance value is generated. In one embodiment, this digital representation may be a six bit or eight bit value.

[0032] FIG. **7** shows an alternative embodiment **700** of the improved solution. In the embodiment **700**, a first trace **710** is formed in close proximity to a second trace **720**. Second trace **720** is coupled to ground. The traces **710** and **720** are electrically isolated, i.e. they are not shorted out. A layer of solder resist may be used to cover traces **710** and **720**. The actuator **510** in combination with the first trace **710** and second trace **720** and solder resist **520** form a three plate capacitor, with two plates **710** and **720** side by side and the actuator acting as the third plate. In this embodiment the actuator does not make DC contact with either plates, allowing easier mechanical alignment during manufacturing, but may reduce the possible capacitance between the plates. Trace **710** is coupled to the measurement device.

[0033] FIG. **8** shows a further alternative embodiment **800** of the improved solution. In the embodiment **800**, a first trace **810**, a second trace **820** and a third trace **830** are formed. The first trace **810** is larger than either the second trace **820** or the third trace **830**. The third trace **830** is coupled to ground. The second trace **820** is coupled to a logic input and the first trace **810** is coupled to the measurement device. A layer of solder resist is formed over plate **810**, but plates **820** and **830** are not covered by solder resist.

[0034] The embodiment **800** operates in the following manner. When the actuator makes contact with the plates **820** and **830**, the conductive actuator shorts them out and forms a DC connection to ground between the plates, which is detected by the logic input. Thus, the embodiment **800** forms both a combination switch and force sensing button.

[0035] In another alternative embodiment **900** shown in FIG. **9**, plate **910** is fully covered with solder resist **520**, and plate **920** is fully uncovered. When actuator **510** is pressed against the substrate, the actuator **510** is therefore grounded and, and a 2-plate capacitor is formed by **910** and **510** with solder resist acting as the dielectric.

[0036] Another alternative embodiment **1000** is shown in FIG. **10**. The embodiment **1000** comprises a first plate **1010**, a second plate **1020**, and a grounded trace **1030** placed between the first plate and the second plate. First plate **1010** and second plate **1020** are covered in solder resist, but trace **1030** is exposed (i.e. no solder resist). This embodiment **1000** is well suited for implementation on a single side PCB board. In another embodiment, a further trace **1040** is present and located between the first plate **1010** and second plate **1020**, where trace **1030** is grounded and trace **1040** is a logic output.

[0037] Embodiments of the present invention are well suited to performing various other steps or variations of the steps recited herein, and in a sequence other than that depicted and/or described herein. In one embodiment, such a process is carried out by processors and other electrical and electronic components, e.g., executing computer readable and computer executable instructions comprising code contained in a computer usable medium.

[0038] For purposes of clarity, many of the details of the improved force sensing actuator and the methods of designing and manufacturing the same that are widely known and are not relevant to the present invention have been omitted from the following description.

[0039] It should be appreciated that reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Therefore, it is emphasized and should be appreciated that two or more references to “an embodiment” or “one embodiment” or “an alternative embodiment” in various portions of this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures or characteristics may be combined as suitable in one or more embodiments of the invention.

[0040] Similarly, it should be appreciated that in the foregoing description of exemplary embodiments of the invention, various features of the invention are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure aiding in the understanding of one or more of the various inventive aspects. This method of disclosure, however, is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the claims following the detailed description are hereby expressly incorporated into this detailed description, with each claim standing on its own as a separate embodiment of this invention.

What is claimed is:

1-20. (canceled)

21. A method comprising:

measuring a capacitance of an actuator and a conductive element when, responsive to a force applied to the actuator, the actuator:

couples to a reference voltage; and

deforms such that a surface area of the actuator in proximity to the conductive element increases; and

determining the force applied to the actuator based on the measured capacitance.

22. The method of claim **21**, wherein the measuring of the capacitance includes measuring the capacitance that increases as the surface area of the actuator in proximity to the conductive element increases.

23. The method of claim **22**, wherein the measuring of the capacitance includes measuring a maximum capacitance when the surface area of the actuator in proximity to the conductive element is a maximum surface area.

24. The method of claim **23**, wherein the determining of the force applied to the actuator, based on the measured capacitance, includes determining a maximum force when the measured capacitance is the maximum capacitance.

25. The method of claim **21**, wherein the measuring of the capacitance includes measuring the capacitance when the actuator is deformed in contact with an insulator covering the conductive element and the actuator is coupled with the reference voltage through contact with an uninsulated portion of another conductive element.

26. The method of claim **21**, wherein the measuring of the capacitance includes using a relaxation oscillator to measure the capacitance.

27. The method of claim **21**, wherein the determining of the force applied to the actuator based on the measured capacitance includes determining the force based on a digital representation of the measured capacitance.

28. A device comprising:

a first conductive element coupled with a reference voltage;

a second conductive element covered by an insulator;

an actuator having a conductive surface, wherein responsive to a force applied to the actuator, the actuator configured to:

couple with the reference voltage through the first conductive element; and

deform in contact with the insulator, wherein the deformation of the actuator increases a surface area of the actuator in proximity to the second conductive element; and

a circuit configured to measure a capacitance of the second conductive element and the actuator, the circuit including a processing element configured to determine the force applied to the actuator, based on the measured capacitance.

29. The device of claim **28**, wherein the capacitance of the second conductive element and the actuator increases as the surface area of the actuator in proximity to the second conductive element increases.

30. The device of claim **29**, wherein the surface area of the actuator in proximity to the second conductive element is a maximum surface area when the force applied to the actuator is at a maximum force.

31. The device of claim **28**, wherein the actuator is configured to couple with the reference voltage through the first conductive element by contact between the conductive surface of the actuator and an uninsulated portion of the first conductive element.

32. The device of claim **31**, wherein the contact between the conductive surface of the actuator and the uninsulated portion of the first conductive element is made prior to the deformation of the actuator in contact with the insulator.

33. The device of claim **28**, wherein the reference voltage is a ground voltage.

34. The device of claim **28**, wherein the first conductive element is located approximately below a center axis of the actuator, and the second conductive element surrounds the first conductive element.

35. The device of claim **28**, wherein the circuit includes a relaxation oscillator to measure a capacitance of the second conductive element and the actuator.

36. The device of claim **28**, wherein the processing element is configured to determine the force applied to the actuator, based on a digital representation of the measured capacitance.

37. A system comprising:

a printed circuit board comprising:

a conductive layer covered by an insulating layer;

a contact coupled to a ground;

a conductive actuator, wherein responsive to a force applied to the conductive actuator, the conductive actuator configured to:

couple to the ground through the contact; and

deform into the insulating layer, wherein the deformation of the conductive actuator increases a surface area of the conductive actuator over the insulating layer and the conductive layer;

a measurement device configured to measure a capacitance of the conductive layer and the electrically grounded conductive actuator; and

one or more processors configured to determine the force applied to the electrically grounded conductive actuator, based on the measured capacitance.

38. The system of claim **37**, wherein responsive to the force applied to the conductive actuator, the conductive actuator is configured to couple to the ground through an exposed portion of the contact that is not insulated.

39. The system of the claim **37**, wherein the conductive layer and the insulating layer at least partially surround the contact.

40. The system of claim **37**, wherein the contact is located approximately below a center axis of the conductive actuator.

* * * * *