

FLEXIBLE SELF-POWERED TOUCHPAD SYSTEMS

RELATED APPLICATION

[0001] This application claims the benefit of priority to the Singapore application no. 10202303616V filed December 22, 2023, the contents of which are hereby incorporated by reference in their entirety for all purposes.

TECHNICAL FIELD

[0002] The present disclosure relates to flexible electronic devices and more particularly to flexible touchpad systems.

BACKGROUND

[0003] Conventional electronics are typically produced in batches using film deposition combined with subtractive nanofabrication techniques such as photolithography and etching. The conventional methods and materials used in these processes are not conducive to flexibility, making it difficult to adapt them for wearable or bendable applications. In contrast, methods often employed in fabricating flexible and stretchable electronics (e.g., pattern transfer, solution-based printing, roll-to-roll processing, and additive manufacturing technologies) necessitate precise cutting of the substrates, flattening using rigid carriers, and meticulous alignment with shadow masks to ensure the films are patterned correctly.

SUMMARY

[0004] In one aspect, a touchpad system includes: a circuit, a substrate, a first layer, and a laser-induced graphene layer. The circuit includes a machine learning module configured to recognize a handwriting input provided by the touch. The first layer is a thin film polymer. The thin film polymer is any one of polytetrafluoroethylene and polyvinylidene fluoride. The laser-induced graphene layer is disposed between the first layer and the substrate. The laser-induced graphene layer and the first layer form a triboelectric nanogenerator. The circuit is powered solely by a voltage response generated by the triboelectric nanogenerator.

[0005] The circuit of the touchpad system may be configured to acquire the voltage response and to use the voltage response acquired as input to the machine learning module and to power the circuit.

[0006] According to another aspect, a method includes: forming a first layer of a thin film polymer, the thin film polymer being any one of polytetrafluoroethylene and polyvinylidene fluoride; using laser direct writing to form a laser-induced graphene layer on a substrate; disposing the laser-induced graphene layer between the first layer and the substrate, the laser-induced graphene layer and the first layer forming a triboelectric nanogenerator; and connecting a circuit to the triboelectric nanogenerator, the circuit including a machine learning module configured to recognize a handwriting input provided by the touch, wherein the circuit is powered solely by a voltage response generated by the triboelectric nanogenerator.

[0007] The method may further include configuring the circuit to acquire the voltage response and to use the voltage response acquired as input to the machine learning module and to power the circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] To aid understanding, various embodiments of the present disclosure will be described with reference to the following figures:

[0009] FIG. 1A is a schematic diagram of a touchpad system according to embodiments of the present disclosure;

[0010] FIG. 1B illustrates the touchpad system of FIG. 1A as an exemplary flexible electronic device;

[0011] FIG. 1C is a graphical representation of a voltage response of the touchpad;

[0012] FIG. 2 is an image of an Arduino Uno board used in making a prototype of the touchpad system;

[0013] FIG. 3 is a schematic diagram of the touchpad system showing more details for the electrical circuit in accordance with embodiments of the present disclosure;

[0014] FIG. 4 is a schematic diagram of the touchpad device showing a layered structure;

[0015] FIG. 5 is a graphical representation of the voltage response generated when the touchpad is touched by different materials;

[0016] FIG. 6 is a schematic diagram to illustrate an example of the LIG pattern used in a prototype of the touchpad system;

[0017] FIG. 7 are graphical representations of the variable voltage response to contact paths of different directions;

[0018] FIG. 8 are examples of the variable voltage response corresponding to different letters of the English language alphabet being written out on the touchpad;

[0019] FIG. 9A is a schematic diagram illustrating an interdigital configuration of an LIG layer of the touchpad system;

[0020] FIG. 9B is a schematic diagram illustrating a crossbar configuration of the LIG layer of the touchpad system;

[0021] FIG. 9C is a schematic diagram illustrating a helix configuration of the LIG layer of the touchpad system;

[0022] FIG. 9D is a schematic diagram illustrating a serpentine configuration of the LIG layer of the touchpad system;

[0023] FIG. 9E is a schematic diagram illustrating a zigzag configuration of the LIG layer of the touchpad system; and

[0024] FIG. 9F is a schematic diagram illustrating a wraparound configuration of the LIG layer of the touchpad system.

DETAILED DESCRIPTION

[0025] The following detailed description is made with reference to the accompanying drawings, showing details and embodiments of the present disclosure for the purposes of illustration. Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments, even if not explicitly described in these other embodiments. Additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0026] In the context of various embodiments, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

[0027] In the context of various embodiments, the term “about” or “approximately” as applied to a numeric value encompasses the exact value and a reasonable variance as generally understood in the relevant technical field, e.g., within 10% of the specified value.

[0028] As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0029] The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any embodiment described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments. As used herein, the singular ‘a’ and ‘an’ may be construed as including the plural “one or more” unless apparent from the context to be otherwise.

[0030] Terms such as “first” and “second” are used in the description and claims only for the sake of brevity and clarity, and do not necessarily imply a priority or order, unless required by the context.

[0031] In the present disclosure, for the purpose of brevity, the term “character” may refer to a letter of the English language alphabet, an Arabic numeral, a character or a word in any other language, a symbol in any one or more sets of symbols, etc. For example, the letter “a” may be referred to as one character and the numeral “8” may be referred to as another character.

[0032] Some methods may be described in terms of steps merely to aid understanding and/or for convenient reference. The delineation between one step and another step may be merely for convenient reference in the present disclosure. It will be understood that in actual implementation there may not be a clear division or transition from one step to another subsequent step. There may be a certain amount of overlap among the steps and/or more than one step may occur or be performed concurrently in time, etc.

[0033] As schematically illustrated in FIG. 1A, a touchpad system 100 includes a touchpad 300 operably connected to or in communication with a circuit 200. For the purpose of many applications, it may be useful to provide a touchpad 300 that is flexible, as illustrated in FIG. 1B.

[0034] When an object, such as a human finger or a pen, touches or presses on a surface of the touchpad 300, the touchpad 300 is configured to generate a voltage response. An example of a voltage response 700 is graphically represented in FIG. 1C. In this example, the touchpad is tapped repeatedly by the same finger. Each positive voltage spike corresponds to an event of the finger tapping once on the touchpad. It is not possible for the human finger to consistently apply an exactly identical amount of force at every tapping event. As shown in FIG. 1C, there is some variation in the voltage response from one tapping event to another tapping event.

[0035] The touchpad system may be made by a method including forming a first layer of a thin film polymer. The method may include using laser direct writing to form the laser-induced graphene (LIG) layer on a substrate. The method may include direct laser writing on a polymer substrate, e.g., polyimide sheets, to enable in-situ formation of graphene on the substrate.

[0036] The method may include disposing the LIG layer between the first layer and the substrate, such that the LIG layer and the first layer form a triboelectric nanogenerator (TENG). The touchpad system may be completed by connecting a circuit to the TENG. The circuit is configured to provide a machine learning module. The machine learning module is configured to recognize a handwriting input provided by the touch. The touchpad system is configured such that the touchpad system, including the circuit, can be powered solely by a voltage response generated by the TENG.

[0037] The circuit 200 may be better understood with reference to FIG. 2 and FIG. 3. The circuit 200 may be embodied at least partially by way of an Arduino Uno board, an image of which is shown in FIG. 2. In the prototype of the touchpad system 100 developed and tested, the Arduino Uno board was configured as a data acquisition system. In some other embodiments, the Arduino Uno board may be replaced by an integrated chip or processor. In yet other embodiments, the Arduino Uno board may be replaced by a printed circuit board configured to include the data acquisition system, the machine learning module, and a wireless communications module.

[0038] In the prototype, which is described herein to aid understanding and not to be limiting, the voltage response from the touchpad 300 is transferred to a converter circuit. The converter circuit was constructed from four diodes (D1 to D4) to improve the precision and reliability of the voltage readings acquired from the touchpad 300.

[0039] The data acquisition system was configured to capture the voltage response (signals) from the touchpad 300, process the voltage response, and subsequently transmit data to a computing unit and/or memory. The data may be transferred via a USB (universal serial bus) connector provided on the Arduino Uno board. For example, the USB connector may be used for data transfer, e.g., with a laptop or a personal computer (PC). The USB connector may serve to connect the Arduino Uno board to a power source, e.g. for the initial set-up.

[0040] The circuit 200 may include one or more processors and one or more memories embodying a machine learning module. A model development and training method may include the following: (i) a data collection stage; (ii) a data pre-processing and feature extraction stage; (iii) a model selection and training stage; (iv) a model evaluation and adjustment stage; and (v) a pattern recognition stage.

[0041] In the data collection stage, different characters are used to train the data, the data include the amplitude of the signal, sampling frequency, time, etc.

[0042] In the data pre-processing and feature extraction stage, the data undergoes pre-processing before model training. This may include data cleaning, feature selection, and feature extraction. Useful features are extracted from the raw data for each sample for model training. Known signal processing techniques and feature extraction algorithms may be used.

[0043] In the model selection and training stage, an appropriate machine learning algorithm, such as support vector machine, neural network, decision tree, random forest, etc., may be chosen. The pre-processed dataset is then used to train the selected model. The model will be trained on the relationship between the signal pattern in different segments and the handwritten characters.

[0044] In the model evaluation and adjustment stage, the model may be evaluated and adjusted as necessary. Model performance may be measured or assessed by metrics such as but not limited to cross-validation, ROC (receiver-operating characteristic) curves, accuracy, recall rates, etc.

[0045] In the pattern recognition stage (or in use), when a character is handwritten on the touchpad, the resulting voltage response is acquired from the touchpad and fed to the model for prediction. Based on the voltage response acquired, the machine learning module is configured to predict the character written on the touchpad. For the purpose of testing the prototype touchpad system, the Arduino Uno board may be programmed in Python to implement a support vector machine algorithm. The touchpad system prototype was found capable of accurately performing handwriting recognition. In other words, based on the above, the touchpad system is configured to recognize handwritten input with an accuracy of close to 100% or with an accuracy that is accurate for practical purposes of correctly distinguishing between the 26 letters of the English language alphabet.

[0046] The conventional touch-sensitive panel utilizes multiple sensors or sensor arrays in just one device. This typically requires a substantial amount of wiring, resulting in a system that involves computational complexity and a dedicated power supply for the sensors and sensor arrays. The conventional touch-sensitive panel works by employing an array of rows and columns of conductive tabs created using a printed circuit board. The printed circuit board is affixed to a surface plastic film with strong double-sided tape or glue. The primary sensing detection mechanism is capacitive sensing. Under the surface of the touchpad, a dedicated integrated circuit board continuously measures and reports the movement path, determining the movement and position of the finger.

[0047] In contrast, the proposed touchpad 300 involves fewer components and is overall more robust and more elegant in concept. FIG. 4 is a schematic diagram illustrating the structural features of the touchpad 300 in greater detail. The touchpad 300 includes a first layer 310, an LIG layer 320, and a substrate 330.

[0048] The first layer 310 is a thin film of a polymer. The first layer 310 may be PTFE (Polytetrafluoroethylene). The first layer 310 may alternatively be PVDF (Polyvinylidene Fluoride).

[0049] The LIG layer may be laser induced graphene (LIG) patterned or fabricated on the substrate. The LIG layer may be formed in a selected pattern, including but not limited to an interdigital configuration. The LIG layer is characterized by good electrical conductivity to collect electrical charges and to transfer the collected electrical charges.

[0050] The substrate is selected from a flexible polymer. In the prototype, the substrate was formed from polyimide (PI) with good results. Various synthetic polymers may be selected, including but not limited to polytetrafluoroethylene (PTFE), poly (ether sulfone) (PES), polyether ether ketone (PEEK).

[0051] Instead of using multiple sensors or sensor arrays, a specially configured triboelectric nanogenerator (TENG) is formed by the LIG layer and first layer in combination. The LIG sensing layer is configured in one or more patterns. By introducing this patterned LIG layer, when the human finger slides across the proposed touchpad in different directions (on the surface of the touchpad), different voltage responses are generated.

[0052] FIG. 5 is a graphical representation of the voltage response generated by the TENG of the prototype touchpad 300 when touched by a human finger, a gloved finger, a

plastic pen, and a metal stick, respectively. The results from the prototype demonstrated that the LIG pattern could enable efficient signal capture and processing, and make the touchpad both responsive and reliable, regardless of the materials of the object used for operating the touchpad. As the experimental data illustrates, the proposed touchpad responds not only to human fingers but also exhibits a similar response to various materials. This indicates that the touchpad can function with more than just a human finger; an operator can use different 'tools', such as a plastic pen, metal pen, or a gloved hand, to input information. This functionality is due to the voltage responses being generated between the LIG layer and the first layer of the touchpad. As long as there is kinetic energy produced by any movement, the kinetic energy will be converted into electrical energy, resulting in a voltage response. Advantageously, the voltage response is not dependent on the electrical conductivity of the object touching the touchpad. This means that the touchpad can be operated by a bare finger or a gloved finger, or it can be operated by a tool made from any of a broad range of materials. In addition, it was noted that a sufficiently large voltage response could be generated such that the touchpad in effect could power itself from the TENG-generated electrical energy. This opens opportunities to configure the touchpad system 100 as a lightweight portable or mobile device.

[0053] FIG. 6 is a schematic diagram to further illustrate a working principle of the touchpad 300 in generating a useful voltage response. The LIG layer 320 is formed in a configuration or pattern 800 of one or more conductive elements 890. The conductive elements or portions of one conductive element 890 are spaced apart from one another.

[0054] The voltage response varies for different directions of a touch 600. The touch 600 may be applied on the first layer, e.g., the first layer may provide an exposed surface for direct physical contact with a human finger or a pen. The opposite surface (e.g., an unexposed surface) of the first layer is in direct contact with the LIG layer 320 in some areas and in direct contact with the substrate in other areas (owing to the patterned nature of the LIG layer). As the touch 600 moves across the touchpad 300 along a direction (e.g., a first direction 601) over a period of time (e.g., tracing out a contact path), there will be a variation in the areas in which the first layer and the LIG layer are pressed closer together and in the other areas where the first layer and the LIG layer are released from being pressed together. The kinetic energy from the touch generates a varying triboelectric effect between the first layer and the LIG layer. The charges generated by the triboelectric effect at any time instant

result in an electrical voltage that is sensed or acquired by the circuit 200 connected to the LIG layer.

[0055] The patterned nature of the LIG layer also increases the variable features of the resulting voltage response. For example, the same character traced over two LIG layers configured with different patterns will produce different voltage responses. The voltage response corresponding to each of different directions of movement of the touch 600 can be configured by configuring the pattern 800. According to various embodiments, the pattern 800 is configured to enable distinctive voltage responses for each of a plurality of directions. Collectively, a touch moving over different parts of the pattern 800 in the course of tracing out or handwriting a character is found to generate a voltage response that is unique to the combination of the directions and sequence of directions of the moving touch.

[0056] FIG. 7 shows graphical representations of the voltage responses 701, 702, 703 obtained experimentally as the touch moved along different directions 601, 602, 603 as shown in FIG. 6. These are merely a few examples shown for illustrative purposes. The exact voltage response 700 may vary for different embodiments of the proposed touchpad 300.

[0057] As one of the applications of the proposed touchpad 300, a handwriting recognition system has been developed. Based on features of the proposed touchpad 300, when handwriting input for a character is provided, according to the stroke order and structure of the character, each character will have a unique pattern. The voltage responses of different characters (e.g., letters and numerals) were collected and stored in a database to train the machine learning models that built for the prototype. The trained machine learning model can determine the letter or number drawn on the surface of the touchpad. Various letter recognition machine learning algorithms can be used, including but not limited to one or more of Support Vector Machines (SVM), k-Nearest Neighbors (KNN), decision trees, Naïve Bayes, etc. The machine learning model may be configured to classify letters of the alphabet based on visual features (e.g., length and direction of strokes forming the shape or visually perceptible features). Examples include but are not limited to code available at https://github.com/spignelon/Letter-Recognition_Project-ML.

[0058] Using the prototype of the proposed touchpad system 100, it was possible to generate a sufficient number of different voltage responses so that each character in a character set or in an alphabet of a language system may be represented by a unique voltage

response. In the experiments, the touchpad system 100 was used to collect 26 multiple voltage responses corresponding to each handwritten letter of the English language alphabet. The machine learning module was trained on the voltage responses for each character. For the exercise, all letters were written in the upper case. It is possible to extend the library to include lower case letters, numerals, and other symbols.

[0059] In use, the touchpad system 100 may generate a string of voltage signals corresponding to a word, a phrase, or a sentence. The machine learning model would be trained to predict or recognize the corresponding individual characters, and output the word or sentence. In other words, the training data is based on voltage responses of individual characters, and the predicted output may be one or more individual characters, or one or more words, phrases, or sentences formed by the one or more characters.

[0060] In a similar manner, it is also possible to build a different library for a different language. For example, a library for the Japanese language system may include training the machine learning model to recognize a hiragana or katakana character based on a voltage response.

[0061] It is also envisioned to extend the proposed touchpad system 100 to build a library of voltage responses in which each voltage response corresponds to a character in a command function for operating a robotic tool or a machine. For example, each of such command functions may be treated as a character or as a composite of multiple characters.

[0062] Reference is now made to FIG. 9A to FIG. 9F which shows different examples of patterns 800 for the LIG layer.

[0063] In the example above, the prototype of the touchpad system 100 was described with the LIG layer in the form of an interdigital pattern 801, merely to aid understanding and for illustrative purposes. As illustrated schematically in FIG. 9A, the interdigital pattern 801 may include two primary conductive elements 811, 814 from which secondary conductive elements 812, 813 extend in an alternating, interleaving manner.

[0064] In some other embodiments, as illustrated in FIG. 9B, the LIG layer may be configured in a pattern 800 that includes a crossbar pattern 802. The crossbar pattern 802 may include conductive elements 821 disposed in an array or grid. Parts of the conductive elements 821 are spaced apart from one another to leave spaces 822 clear of conductive elements.

[0065] In some other embodiments, as illustrated in FIG. 9C, the LIG layer may be configured in a pattern 800 that includes a helix pattern 803. The helix pattern 803 may be configured as a spiral of a conductive element 831 with portions of the spiral spaced apart to form spaces 832 therebetween.

[0066] In some other embodiments, as illustrated in FIG. 9D, the LIG layer may be configured in a pattern 800 that includes a serpentine pattern 804. The serpentine pattern 804 may be configured with parallel portions of a conductive element 841 spaced apart to form spaces 842 therebetween.

[0067] In some other embodiments, as illustrated in FIG. 9E, the LIG layer may be configured in a pattern 800 that includes a zigzag pattern 805. The zigzag pattern 805 may be configured as a sawtooth configuration with portions of conductive elements 851, 853 spaced apart to define an array of closed triangular spaces 852 and open spaces 854. Each space 852, 854 is clear of conductive elements.

[0068] In some other embodiments, as illustrated in FIG. 9F, the LIG layer may be configured in a pattern 800 that includes a wraparound pattern 806. The wraparound pattern 806 may be configured as a box maze-like configuration with portions of conductive elements 861 spaced apart to define one or more spaces 862. A space 862 may be in the shape of a path with angles or corners 863. Each space is clear of conductive elements.

[0069] In some embodiments, the LIG layer may be configured as a combination of any one or more of the various patterns described. The patterns 800 described are merely for illustrative purposes and the LIG layer is not limited to being configured according to these few examples. The exact configuration of the LIG layer may be determined according to the maximum number of unique or distinctive voltage responses or characters to be recognized.

[0070] The proposed touchpad system has been described above in the context of primarily functioning as a handwriting recognition system. By altering the LIG pattern fabricated on the substrate, the functionality of the touchpad can be extended to other useful and practical applications.

[0071] For example, the touchpad can be configured as a security key. For example, the touchpad may be configured to recognize a specific pre-recorded pattern. Upon identifying a handwriting input to be the same as the specific pre-recorded pattern, the touchpad may communicate (e.g., wirelessly) to unlock a locked device. The proposed touchpad system may be used in such and other secured access and authentication scenarios.

[0072] In another example, the touchpad may be configured to capture specific finger motions and, in response thereto, enable remote control or the transmission of specific commands to a robot or other machines. This adaptability underscores the touchpad's potential for a wide range of applications beyond simple handwriting recognition.

[0073] The versatility of such a flexible and self-powered touchpad extends the potential applications across many industrial applications, including but not limited to areas like health monitoring, interactive wearables, smart textiles, etc. Envisioned applications of the touchpad system range from serving as an energy generator for small electronic devices to being integrated into wearable sensors and microrobots. The inherent flexibility and self-powering capability make the proposed touchpad an ideal choice for devices that require adaptability and autonomy in energy sourcing.

[0074] According to one aspect, the present disclosure describes various embodiments of a touchpad system responsive to a touch. The touchpad system includes: a circuit, a substrate, a first layer, and a laser-induced graphene (LIG) layer. The circuit includes a machine learning module configured to recognize a handwriting input provided by the touch. The first layer is a thin film polymer. The thin film polymer is any one of polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF). The LIG layer is disposed between the first layer and the substrate. The LIG layer and the first layer form a triboelectric nanogenerator (TENG). The circuit is powered solely by a voltage response generated by the TENG.

[0075] The circuit of the touchpad system may be configured to acquire the voltage response and to use the voltage response acquired as input to the machine learning module and to power the circuit.

[0076] In some embodiments, the substrate of the touchpad system is polyimide. In other embodiments, the substrate of the touchpad system is polyethylene. In yet other embodiments, the substrate of the touchpad system is polycarbonate.

[0077] The LIG layer of the touchpad system may be formed in one or more patterns, and the voltage response may vary for different directions of the touch on the first layer.

[0078] In some embodiments, the one or more patterns may include an interdigital configuration. In some embodiments, the one or more patterns may include a crossbar configuration. In some embodiments, the one or more patterns may include any one or more

of the following: a helix configuration, a serpentine configuration, a zigzag configuration, a wraparound configuration, or any combination thereof.

[0079] In the touchpad system, the machine learning module may be trained to determine a character in the handwriting input based on the voltage response. The character may be any one of a letter or a number.

[0080] According to another aspect, the present disclosure describes various embodiments of a method of making a touchpad system responsive to a touch. The method includes: forming a first layer of a thin film polymer, the thin film polymer being any one of polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF); using laser direct writing to form a laser-induced graphene (LIG) layer on a substrate; disposing the LIG layer between the first layer and a substrate, the LIG layer and the first layer forming a triboelectric nanogenerator (TENG); and connecting a circuit to the TENG, the circuit including a machine learning module configured to recognize a handwriting input provided by the touch, wherein the circuit is powered solely by a voltage response generated by the TENG.

[0081] The method may further include configuring the circuit to acquire the voltage response and to use the voltage response acquired as input to the machine learning module and to power the circuit.

[0082] In the method, the substrate may be any one selected from the group consisting of: polyimide, polyethylene, and polycarbonate.

[0083] In the method, the LIG layer may be formed in one or more patterns, and wherein the voltage response varies for different directions of the touch on the first layer.

[0084] The method may further include forming the LIG layer as one or more patterns, wherein the one or more patterns is selected from the group consisting of: an interdigital configuration, a crossbar configuration, a helix configuration, a serpentine configuration, a zigzag configuration, a wraparound configuration, or any combination thereof.

[0085] The method may further include training the machine learning module using a plurality of voltage responses corresponding to a plurality of different characters.

[0086] Each character in the handwriting input is associated with a respective one of the plurality of voltage responses.

[0087] The machine learning module is trained to determine each of the plurality of different characters.

[0088] Each of the plurality of different characters is any one of a letter or a number.

[0089] All examples described herein, whether of apparatus, methods, materials, or products, are presented for the purpose of illustration and to aid understanding, and are not intended to be limiting or exhaustive. Modifications may be made by one of ordinary skill in the art without departing from the scope of the claimed invention.

CLAIMS

1. A touchpad system responsive to a touch, comprising:
 - a circuit, the circuit including a machine learning module configured to recognize a handwriting input provided by the touch;
 - a substrate;
 - a first layer, the first layer being a thin film polymer, the thin film polymer being any one of polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF); and
 - a laser-induced graphene (LIG) layer, the LIG layer being disposed between the first layer and the substrate, wherein the LIG layer and the first layer form a triboelectric nanogenerator (TENG), and wherein the circuit is powered solely by a voltage response generated by the TENG.
2. The touchpad system as recited in claim 1, wherein the circuit is configured to acquire the voltage response and to use the voltage response acquired as input to the machine learning module and to power the circuit.
3. The touchpad system as recited in claim 2, wherein the substrate is polyimide.
4. The touchpad system as recited in claim 2, wherein the substrate is polyethylene.
5. The touchpad system as recited in claim 2, wherein the substrate is polycarbonate.
6. The touchpad system as recited in any one of claims 2 to 5, wherein the LIG layer is formed in one or more patterns disposed on the first layer, and wherein the voltage response varies for different directions of the touch on the first layer.
7. The touchpad system as recited in claim 6, wherein the one or more patterns comprise an interdigital configuration.
8. The touchpad system as recited in claim 6, wherein the one or more patterns comprise a crossbar configuration.

9. The touchpad system as recited in claim 6, wherein the one or more patterns comprise any one or more of the following: a helix configuration, a serpentine configuration, a zigzag configuration, a wraparound configuration, or any combination thereof.
10. The touchpad system as recited in claim 6, wherein the machine learning module is trained to determine a character in the handwriting input based on the voltage response.
11. The touchpad system as recited in claim 10, wherein the character is any one of a letter or a number.
12. A method of making a touchpad system responsive to a touch, comprising:
forming a first layer of a thin film polymer, the thin film polymer being any one of polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF);
using laser direct writing to form a laser-induced graphene (LIG) layer on a substrate;
disposing the LIG layer between the first layer and the substrate, the LIG layer and the first layer forming a triboelectric nanogenerator (TENG); and
connecting a circuit to the TENG, the circuit including a machine learning module configured to recognize a handwriting input provided by the touch, wherein the circuit is powered solely by a voltage response generated by the TENG.
13. The method as recited in claim 12, further comprising: configuring the circuit to acquire the voltage response and to use the voltage response acquired as input to the machine learning module and to power the circuit.
14. The method as recited in claim 13, wherein the substrate is any one selected from the group consisting of: polyimide, polyethylene, and polycarbonate.
15. The method as recited in claim 12, wherein the LIG layer is formed in one or more patterns, and wherein the voltage response varies for different directions of the touch on the first layer.

16. The method as recited in claim 15, further comprising forming the LIG layer as one or more patterns, wherein the one or more patterns is selected from the group consisting of: an interdigital configuration, a crossbar configuration, a helix configuration, a serpentine configuration, a zigzag configuration, a wraparound configuration, or any combination thereof.

17. The method as recited in claim 13, further comprising: training the machine learning module using a plurality of voltage responses corresponding to a plurality of different characters.

18. The method as recited in claim 17, wherein each character in the handwriting input is associated with a respective one of the plurality of voltage responses.

19. The method as recited in claim 17, wherein the machine learning module is trained to determine each of the plurality of different characters.

20. The method as recited in claim 17, wherein each of the plurality of different characters is any one of a letter or a number.