SUMMARY

[0006] Provided herein *inter alia* are "smart" dendrometers that allow farmers, gardeners, landscapers, municipal plant managers, land managers, forest managers or anyone to monitor the growth of a plant over short and long periods. These devices can show the change in plant size that may occur due to sap flow as well as growth over the course of a day, hour, or even a few seconds to minutes. Over longer terms, these devices can provide data as to the health of the plant and if intervention may be needed. These devices, which are low-cost to manufacture, can be installed for long periods of time without maintenance, can be sealed for the life of the device, do not require battery replacement for the life of the device, and can provide a variety of real-time data on size changes (down to micron resolution) as well as temperature, humidity, light, and so forth. Moreover, as described herein, they can be fitted to a variety of plant types and parts.

[0007] To achieve these goals and make them possible for widespread use, provided herein are devices that are very low cost and can precisely measure plant part diameters of a wide variety of plants of many sizes. These devices can also transfer that data to a mobile device, server, or other computer system (*e.g.*, wirelessly, directly, or via a network/server) that makes the data available easily and in a way that can be used simply to make decisions or as part of an automatic control system for irrigation or fertilization.

[0007a] In an aspect, the present disclosure refers to a sensor for measuring plant part size and/or other plant part characteristics, comprising:

a) one or more fasteners configured to be positioned in or around a plant part;

b) two or more components selected from the group consisting of: a dendrometer, an accelerometer, an air temperature sensor, a humidity sensor, and a light sensor;

c) a processor; and

d) a power supply.

[0007b] In an aspect, the present disclosure refers to a system for measuring plant part size and/or other plant part characteristics, comprising:

a) a sensor according to the above aspect; and

b) a mobile device and/or server;

wherein the sensor is connected to the mobile device and/or server via wireless communication and configured to transmit data to the mobile device and/or server; and optionally wherein the sensor is connected to the mobile device and/or server via Bluetooth low energy (BLE), Long Range (LoRa), Near Field Communication (NFC), or a combination thereof.

[0007c] In an aspect, the present disclosure refers to a system for measuring plant part size and/or other plant part characteristics of a plurality of plants, comprising a plurality of sensors according to the above aspects; wherein each sensor of the plurality is configured to measure plant part size and/or other plant part characteristics of a single plant of the plurality; and wherein the system optionally further comprises:

(a) a mobile device; wherein each sensor of the plurality is connected to the mobile device and configured to transmit data to the mobile device; and/or

(b) a server; wherein each sensor of the plurality is connected to the server and configured to transmit data to the mobile device.

[0007d] In an aspect, the present disclosure refers to a method for measuring size of a plant part and/or other plant part characteristics, comprising:

a) affixing a sensor according to the above aspects to the plant part; and

b) measuring size and/or other plant part characteristics of the plant part based at least in part on data collected from the two or more components of the sensor;

wherein optionally the size and/or other plant part characteristics of the plant part is measured at a first time, and the method further comprises measuring size and/or other plant part characteristics of the plant part at a second time different from the first time, wherein the measurement of size and/or other plant part characteristics at the second time is based at least in part on data collected from the two or more components of the sensor.

[0008] In certain examples, provided herein are sensors for measuring plant part size and/or other plant part characteristics, comprising: one or more fasteners configured to be positioned in or around a plant part; two or more components selected from the group consisting of: a dendrometer, an accelerometer, an air temperature sensor, a humidity sensor, and a light sensor; a processor; and a power supply.

[0009] In some examples, the processor comprises a printed circuit board (PCB). In some examples, one or both of the two or more components is/are affixed to the PCB. In some examples, all of the two or more components are affixed to the PCB. In some examples, the PCB comprises an epoxy-fiberglass composite material.

[0010] In some examples, the power supply comprises a battery. In some examples, the battery is a coin cell battery. In some examples, the battery is affixed to the PCB. In some examples, the power supply comprises a solar panel. In some

examples, the power supply comprises an integrated solar panel, hybrid capacitor, and lithium battery. In some examples, the solar panel is affixed to the PCB.

[0011] In some examples, the sensor further comprises a housing, *e.g.*, that encloses at least the processor and power supply. In some examples, the housing is or comprises plastic, *e.g.*, molded plastic. In some examples, the housing is or comprises a polymer resin. In some examples, the plastic or polymer resin is glass-filled. In some examples, the plastic or polymer resin comprises about 10 to about 40% glass, *e.g.*, about 30% glass. In some examples, the processor and magnetometer are enclosed in a sealed, overmolded housing comprising an O-ring. In some examples, the overmolded housing comprises a removable lid covering the battery. In some examples, the housing is a single piece of overmolded plastic that lacks a seal, junction, or fastener.

[0012] In some examples, the sensor comprises a dendrometer. In some examples, the dendrometer comprises: a plunger having a cap and a shaft, wherein the cap is configured to be positioned against the plant part, and wherein the plunger is configured to move laterally in proportion to a change in plant size when the cap is positioned against the plant part; a magnet attached to or within the shaft, wherein the magnet is configured to move laterally in association with the plunger; and a magnetometer configured to detect position of the magnet. In some examples, the magnetometer is configured to detect position of the magnet along multiple axes, a radial axis, or a single plane. In some examples, the magnetometer is configured to detect position of the magnet at micron-scale resolution. In some examples, the magnetometer is configured to detect position of the magnet along multiple axes, *e.g.*, along a radial axis. In some examples, the magnetometer is configured to detect position of the magnet using a ratiometric measurement.

[0013] In some examples, the sensor is configured to measure change in diameter or radius of the plant part. In some examples, the sensor is configured to measure plant part size multiple times per day or at an interval of 15 minutes, 5 minutes, 5 seconds, between 5 seconds and 1 hour, or between 5 seconds and 15 minutes. In some examples, the magnet is neodymium magnet. In some examples, the processor comprises a PCB, and wherein the magnetometer is affixed to the PCB.

[0014] In some examples, the sensor comprises an accelerometer. In some examples, the accelerometer is a 3-axis accelerometer. In some examples, the processor comprises a PCB, and the accelerometer is affixed to the PCB. In some examples, the sensor comprises a light sensor. In some examples, the processor comprises a PCB, and the light sensor is affixed to the PCB. In some examples, the sensor comprises a humidity sensor. In some examples, the processor comprises a PCB, and the humidity sensor is affixed to the PCB. In some examples, the sensor comprises an air temperature sensor. In some examples, the processor comprises a PCB, and the air temperature sensor is affixed to the PCB.

[0015] In some examples, the sensor comprises a dendrometer and one or more of: an accelerometer, an air temperature sensor, a humidity sensor, and a light sensor. In some examples, the sensor comprises a dendrometer, an accelerometer, an air temperature sensor, a humidity sensor, and a light sensor.

[0016] In some examples, the sensor further comprises a transmitter or transceiver. In some examples, the transmitter is a Bluetooth radio or transceiver, *e.g.*, a Bluetooth Low Energy (BLE) radio or transceiver. In some examples, the transmitter is a Long Range (LoRa) transceiver. In some examples, the transmitter is a Near Field Communication (NFC) transceiver. In some examples, the transmitter is affixed to the PCB.

[0017] In some examples, the one or more fasteners comprises a screw, threaded rod, or nail, and wherein the screw, threaded rod, or nail is configured to be positioned within the plant part and mount the sensor to the plant part. In some examples, the one or more fasteners comprises one or more curved arm(s), wherein the curved arm(s) are configured to be positioned around the plant part. In some examples, the one or more fasteners comprises two curved arms arranged in a U- or V-shape. In some examples, the curved arm(s) are configured to be positioned around the plant part opposite the plunger cap. In some examples, the one or more fasteners further comprises an elastic band configured to be wrapped around the sensor and the plant part. In some examples, the screw, threaded rod, or nail comprises stainless steel, brass, aluminum, or titanium. In some examples, the sensor further comprises a nut configured to be positioned around the screw between the sensor and the plant part. In some examples, the sensor further comprises a second nut configured to be positioned around the screw on a face of the sensor distal to the plant part.

In some examples, the one or more fasteners comprises a screw having a first end and a second end, and the sensor further comprises a compression-limiting element having a first opening and a second opening; and a captive screw; wherein the first end of the screw is configured to be positioned within the plant part and mount the sensor to the plant part; wherein the first opening of the compression-limiting element is configured to receive the second end of the screw; and wherein the second opening of the compression-limiting element is configured to receive the captive screw. In some examples, the sensor further comprises a retaining ring configured to be positioned around the captive screw. In some examples, the sensor further comprises a first nut configured to be positioned around the threaded rod between the plant part and the sensor and a second nut configured to be positioned around the threaded rod adjacent to the sensor and distal to the plant part. In some examples, the sensor further comprises a hollow shuttle positioned around the plunger shaft. In some examples, the plunger cap further comprises a gimbal. In some examples, the plunger cap is or comprises molded plastic. In some examples, the plunger cap is less than about 3mm in thickness. In some examples, the plunger cap is configured to contact the plant part over a surface area of between about 10 mm^2 and about 100 mm^2. In some examples, the sensor further comprises a spring around or affixed to the plunger. In some examples, the sensor further comprises a pull tab attached to the plunger shaft opposite the plunger cap. In some examples, the plunger shaft comprises aluminum or stainless steel. In some examples, the plunger shaft is a partly or fully hollow cylinder, and the magnet is a cylindrical magnet positioned inside the plunger shaft.

[0018] In some examples, the plant is a tree or woody plant. In some examples, the plant part is a stem, trunk, bole, or branch. In some examples, the plant is a crop tree. In some examples, the plant is a citrus, olive, nut, cacao, oak, pine, redwood, "strawberry," or maple tree. In some examples, the plant is a vine. In some examples, the plant part is a trunk, shoot, branch, cane, fruit, or stem. In some examples, the vine is a grape vine.

[0019] In certain examples, provided herein are sensors for measuring plant part size, comprising: a) one or more fasteners configured to be positioned around a plant part, wherein the one or more fasteners comprise(s) a rotatable element, and the rotatable element is configured to rotate in proportion to a change in plant size when positioned around a plant part; b) a magnet, wherein the magnet is configured to rotate in accordance with the rotatable

element; c) a rotational sensor configured to detect rotation of the magnet; d) a processor; and e) a power supply.

[0020] In some examples according to any of the examples described herein, the magnet is configured such that a North-South pole axis of the magnet is perpendicular to a rotational axis of the rotatable element. In some examples, the rotational sensor is a Hall sensor. In some examples, the Hall sensor is positioned such that a Z-axis of the Hall sensor is parallel with a rotational axis of the rotatable element. In some examples, the degree of rotation of the rotatable element is linear relative to plant part size by a constant factor. In some examples, the constant factor is about 10 degrees of rotation of the rotatable element per about 1 mm of plant part size change. In some examples, the constant factor is constant over a dynamic range of plant part size. In some examples, the dynamic range of plant part size is from about 4 mm to 24 mm in diameter.

[0021] In some examples, the one or more fasteners comprise(s) at least a first stationary arm having a base and a rotatable arm having a base, wherein the magnet is positioned within the rotatable arm, and wherein change in size of the plant part causes rotation of the rotatable arm. In some examples, the at least first stationary arm and rotatable arm are curved. In some examples, the at least first stationary arm and rotatable arm are curved in opposing directions. In some examples, the plant part is contacted by three lines of contact, wherein first line is on the first stationary arm, wherein the second line is on the rotatable arm, and wherein the third line is on the sensor opposite the first and/or second line(s). In some examples, the sensor further comprises a torsion spring, wherein the torsion spring is connected to the first stationary arm and the rotatable arm. In some examples, the base of the rotating arm and the base of the first stationary arm are connected at a hinge comprising the torsion spring. In some examples, the position of the base of the first stationary arm is configured to slide relative to the base of the rotational arm, such that sliding the base of the first stationary arm a greater distance from the base of the rotational arm causes an increase in the minimum diameter that can be measured by the sensor and a decrease in the minimum change in size that can be measured by the sensor. In some examples, the rotational sensor is positioned within a housing of the sensor. In some examples, the one or more fasteners further comprise a second stationary arm. In some examples, the rotational sensor is positioned within the second stationary arm.

[0022] In some examples, the one or more fasteners comprise(s) a clip and a flexible tape with a first end and a second end; wherein the first end is attached to a rotatable drum, wherein the magnet is positioned within the rotatable drum; wherein the second end is configured to be attached with the clip to the sensor; wherein a first section of the flexible tape comprising the first end is configured to be spooled around the rotatable drum; wherein a second section of the flexible tape comprising the second end is configured to be wrapped around the plant part and attached to the sensor with the clip at the second end; and wherein the rotatable drum is configured to rotate in proportion to the change in size of the plant part. In some examples, the flexible tape comprises a perforated material, polyethylene terephthalate glycol (PETG), a fluorinated material, a composite material, or any combination thereof. In some examples, the composite material comprises Kevlar, fiberglass, or a combination thereof.

[0023] In some examples, the one or more fasteners comprise(s) a ribbon, a clasp, and a rotatable drum, wherein the magnet is positioned within the rotatable drum; wherein the ribbon is configured to be wrapped around the plant part and fastened to the sensor with the clasp; wherein the rotatable drum is configured to rotate in proportion to the change in change in size of the plant part. In some examples, the sensor further comprises a torsion spring; wherein the torsion spring is connected to the rotatable drum; and wherein the torsion spring applies torsion to the rotatable drum or a connection to the sensor thereto.

[0024] In some examples, the one or more fasteners comprise(s) a belt with a plurality of teeth, a clasp, and a toothed pulley, wherein the magnet is positioned within the toothed pulley; wherein the belt is configured to be wrapped around the plant part and fastened to the sensor with the clasp; wherein the toothed pulley is configured to interlock with one or more of the teeth of the belt and rotate in proportion to the change in size of the plant part. In some examples, the belt comprises Kevlar, metal, fiberglass fibers, or a combination thereof. In some examples, the teeth are spaced about 2 mm apart. In some examples, the rotational sensor is positioned within a housing of the sensor.

[0025] In some examples according to any of the examples described herein, the sensor further comprises a transmitter. In some examples, the transmitter is a Bluetooth radio or transceiver, *e.g.*, a Bluetooth Low Energy (BLE) radio or transceiver. In some examples, the sensor further comprises a housing. In some examples, the housing is or comprises molded plastic. In some examples, the rotational sensor, the processor,

and/or the power supply are positioned within the housing. In some examples, the power supply comprises a battery and/or a solar panel. In some examples, the processor comprises a printed circuit board (PCB). In some examples, the sensor further comprises a visual identifier. In some examples, the visual identifier is a QR code or a bar code. In some examples, the sensor further comprises a radio-frequency identification (RFID) tag. In some examples, the plant part is a stem, bole, shoot, cane, body, branch, vine, trunk, or fruit of the plant.

[0026] In other examples, provided herein are systems for measuring plant part size and/or other plant part characteristics, comprising: a sensor according to any one of the above examples; and a mobile device or server; wherein the sensor is connected to the mobile device or server via wireless communication and configured to transmit data to the mobile device or server. In some examples, the sensor is connected to the mobile device or server via Bluetooth low energy (BLE), Long Range (LoRa), or a combination thereof. In some examples, the sensor is configured to transmit data to the mobile device or server. In some examples, the sensor is configured to transmit data related to the rotational sensor, plant part size, wireless communication signal strength, or a combination thereof to the mobile device or server. In some examples, the system comprises a plurality of sensors according to any one of the above examples; wherein each sensor of the plurality is connected to the mobile device or server via wireless communication and configured to transmit data to the mobile device or server. In some examples, each sensor of the plurality is connected to the mobile device or server via Bluetooth low energy (BLE), Long Range (LoRa), or a combination thereof. In some examples, each sensor in the plurality is configured to transmit data related to wireless communication signal strength to the mobile device or server. In some examples, the mobile device comprises a GPS sensor. In some examples, the GPS sensor is configured to obtain location information using the GPS sensor and associate the location information with a sensor of the plurality. In some examples, the mobile device comprises a camera or other image sensor. In some examples, the sensor is configured to transmit data related to one or more of: the magnetometer, plant part size, wireless communication signal strength, accelerometer, light sensor, humidity sensor, air temperature sensor, or a combination thereof to the mobile device and/or server. In some examples, the system further comprises a server, wherein each sensor of the plurality is connected to the server and configured to transmit data to the mobile device.

[0027] In other examples, provided herein is a method for tracking plant part size and/or other plant part characteristics, comprising: measuring size and/or other plant part characteristics of the plant part using a sensor of the present disclosure, wherein the measurement is based at least in part on data collected by the component(s) of the sensor. In some examples, the method comprises, prior to the measurement, mounting the sensor to the plant or plant part, wherein the one or more fasteners is/are positioned in or around the plant part. In some examples, the method further comprises measuring size and/or other plant part characteristics of the plant part using a sensor of the present disclosure at a second time after the first time, wherein the measurement of size and/or other plant part characteristics at the second time is based at least in part on data collected by the component(s) of the sensor.

[0028] In other examples, provided herein are methods for tracking plant part size and/or other plant part characteristics, comprising: a) at a first time, measuring plant part size and/or other plant part characteristics at a sensor or system according to any one of the above examples; and b) at a second time after the first time, measuring plant part size and/or other plant part characteristics at the sensor or system. In some examples, the methods comprise measuring size and/or other plant part characteristics of a plurality of plant parts, *e.g.*, using a system of the present disclosure.

[0029] It is to be understood that one, some, or all of the properties of the various embodiments described herein may be combined to form other embodiments of the present invention. These and other aspects of the invention will become apparent to one of skill in the art. These and other embodiments of the invention are further described by the detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] The present application can be understood by reference to the following description taken in conjunction with the accompanying figures.

[0031] **FIG. 1A** depicts a vertical section view of a clip dendrometer, in accordance with some embodiments.

[0032] **FIG. 1B** depicts top views of a clip dendrometer with three sized stems, in accordance with some embodiments. Dots represent nominal lines of contact with a