

TITLE OF INVENTION

[001] Smart Water Sensor

CROSS REFERENCE TO RELATED APPLICATIONS

[002] NONE

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[003] Not Applicable

REFERENCE TO SEQUENCE LISTING, A TABLE, OR A COMPUTER PROGRAM LISTING COMPACT DISC APPENDIX

[004] Not Applicable

BACKGROUND OF THE INVENTION

[005] The present invention is related to smart water sensors for monitoring water use in a planter and facilitating automation irrigation.

BRIEF SUMMARY OF THE INVENTION

[006] An embodiment of the present invention is a smart water sensor for monitoring water consumption in a planter comprising a microcontroller comprising a controller and a processing module, a detector housing having a bottom end, a top water detector, and a bottom water detector placed within the detector housing at the bottom end. The microcontroller is associated with a memory configured to store watering parameters; The watering parameters comprise information representative of water requirements and water delivery system for a planter. The smart water sensor is configured to be placed in a planter water reservoir with the bottom end in proximity to a planter reservoir bottom. The top water detector defines a top water level of a water volume in the planter water reservoir, and the bottom water detector defines a bottom water level of the water volume in the planter water reservoir. The top water detector is configured to detect water presence and water absence at the top water level and to produce a top detector wet signal indicative of water presence at the top water level. The bottom water detector is configured to detect water absence and water presence at the bottom water level and to produce a bottom detector dry signal indicative of water absence at the bottom water level. The microcontroller is configured to receive the top detector wet signal and the bottom detector dry signal, determine a water full timestamp associated with the top detector wet signal, determine a water consumed timestamp associated with the bottom detector dry signal, calculate a dewatering duration as a function of a time elapsed between the water full timestamp and the water consumed timestamp, and calculate a

planter drink rate as a ratio of the predetermined volume of water and the dewatering duration.

[007] In another embodiment the top water detector is further configured to produce a top detector signal indicative of water presence or water absence at the top water level. The top detector signal is one of the top detector wet signal or a top detector dry signal and the top detector dry signal is indicative of water absence at the top water level. The bottom water detector is further configured to produce a bottom detector signal indicative of water presence or water absence at the bottom water level. The bottom detector signal is one of a bottom detector wet signal or the bottom detector dry signal, and the bottom detector wet signal is indicative of water presence at the bottom water level. The controller is configured, at a regular data acquisition interval, to cause the top water detector to produce the top detector signal and the bottom water detector to produce the bottom detector signal. The processing module is configured to receive the top detector signal and the bottom detector signal, associate the bottom detector signal and the top detector signal with a timestamp, and add the timestamp, the top detector signal, and the bottom detector signal to a detector signal timeseries. Responsive to receiving the top detector signal and the bottom detector signal, the processing module is configured to identify one of a top detector dry-to-wet transition signal, a bottom detector wet-to-dry transition signal, and combinations thereof, determine the water full timestamp as a timestamp associated with the top detector dry-to-wet transition signal, and determine the water consumed timestamp as a timestamp associated with the bottom detector wet-to-dry transition signal. The top detector dry-to-wet transition signal is a top detector wet signal preceded in the detector signal timeseries by a top detector dry signal, and the bottom detector wet-to-dry transition signal is a bottom detector dry signal in the detector signal timeseries by a bottom detector wet signal.

[008] In another embodiment the bottom water detector comprises a bottom emitter, a bottom reflector, and a bottom receiver. The bottom emitter, the bottom reflector, and the bottom receiver are configured so that a bottom electromagnetic wave emitted by the bottom emitter is reflected from the bottom reflector and is received at the bottom receiver. The bottom water detector is placed within the detector housing so that the bottom emitter emits the bottom electromagnetic wave downward towards the planter reservoir bottom, and the bottom receiver is configured to produce the bottom detector signal representative of a reflected portion of the bottom electromagnetic wave received at the bottom receiver. The bottom detector signal is a bottom detector dry signal when

the bottom reflector is not immersed in water and is the bottom detector wet signal when the bottom reflector is immersed in water. The top water detector comprises a top emitter, a top reflector, and a top receiver. The top detector is positioned within the detector housing so that the top emitter emits a top electromagnetic wave perpendicular to the longitudinal axis of the detector housing. The top receiver is configured to produce the top detector signal representative of a reflected portion of the top electromagnetic wave received at the top receiver and the top detector signal is a top detector dry signal when the top detector is not immersed in water and is the top detector wet signal when the top detector is immersed in water. The reflected portion is a dry reflected portion and a wet reflected portion. The top reflector and the bottom reflector when immersed in air reflect the dry reflected portion of the top and bottom electromagnetic waves, respectively. The top reflector and the bottom reflector when immersed in water reflect a wet reflected portion of the top and bottom electromagnetic waves, respectively. The dry reflected portion is sufficiently different from the wet reflected portion so that the top detector dry signal and the bottom detector dry signal are detectably different from the top detector wet signal and the bottom detector wet signal, respectively.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[009] The advantages and features of the present invention will be better understood as the following description is read in conjunction with the accompanying drawings, wherein:

[010] Fig. 1 is a diagram of an embodiment of the present invention.

[011] Fig. 1A is a diagram of an embodiment of the present invention.

[012] Fig. 2 is a diagram of an embodiment of the present invention.

[013] Fig. 3 is a diagram of an embodiment of the present invention.

[014] Fig. 4 is a diagram of an embodiment of the present invention.

[015] Fig. 5 is a diagram of a water detector according to an embodiment of the invention.

[016] Fig. 6 is a diagram of a water detector according to an embodiment of the invention.

[017] Fig. 7 is a diagram of water detector signals according to an embodiment of the invention.

[018] For clarity purposes, all reference numerals may not be included in every figure.

DETAILED DESCRIPTION OF THE INVENTION

[019] Figures 1 and 2 illustrate an embodiment of a smart water sensor 1 comprising a detector housing 4 having a bottom end 4a, and an outer sleeve 2 having a bottom portion 2a that is water permeable (illustrated with vertical slots in Fig. 2). Smart water sensor 1 also may comprise a power source (not shown) (e.g., battery, external power, etc.), a microcontroller 10, a memory 11, a wireless transceiver 12 associated with water sensor id 14, a real time clock 13 and water detectors 120. Water detectors 120 may include a bottom (or first) water detector 120a and a top (or second) water detector 120b. Microcontroller 10 is electrically connected to water detectors 120 and wireless transceiver 12 and is configured to receive detector signals 125 indicative of the water level relative to each water detector 120. Memory 11 may store water sensor id 14 and one or more watering parameters 21 indicative of water requirements of a planted planter, based on types of plants, environmental conditions, abilities of planter 150 water delivery system (e.g., pump flow rates), and various other factors. Watering parameters 21 may comprise a moisture level 22 and a planter multiple 23.

[020] Microcontroller 10 may comprise a controller 10a and a processing module 10. Controller 10a and processing module 10 may be implemented as embedded software instruction, as hardware logic, or as a combination of both. As explained in more detail below, controller 10a may be configured to control smart water sensor 1 while processing module 10b may be configured to process data (e.g., detector signals 125 received at the processing module) and perform calculations and operations. In some embodiments controller 10a and processing module 10b merely refer to a logical division of functionality. In other embodiments, controller 10a may be an onboard microcontroller 10a located inside detector housing 4, and processing module 10b be part of a remote microcontroller 10b. In such embodiments, microcontroller 10 comprises an onboard controller microcontroller 10a (for clarity referred to as either controller 10a or onboard microcontroller 10a) and a remote processing module microcontroller 10b (for clarity referred to as either processing module 10b or remote microcontroller 10b). Controller 10a and processing module 10b are configured to communicate with each other either by programmatically exchanging information when they are logical portions of a single hardware microcontroller 10 as illustrated in Fig. 1, or through wireless communication between onboard microcontroller 10a and remote microcontroller 10b utilizing wireless transceiver 12 as illustrated in Fig. 3.

[021] Embodiments of the invention may utilize smart water sensor 1 placed to monitor for water presence or absence at various levels in a container 151, such as a water

reservoir 151 in a planter 150, as illustrated in Fig. 4. Smart water sensor 1 may be placed in planter water reservoir 151 so that the bottom end 4a is either on, or in proximity to, the planter reservoir bottom. Planter 150 may be outfitted with a watering insert 154 supporting the soil (represented by grid in Fig. 4) and forming planter water reservoir 151 below watering insert 154. Watering insert 154 may comprise plant root “cups” and wicking material facilitating delivery of water from planter water reservoir 151 to the soil. Watering insert 154 may also comprise an opening 154a configured to securely insert outer sleeve 2 so that smart water sensor 1 may be securely positioned inside outer sleeve 2 to monitor for water presence and absence in planter water reservoir 151.

[022] Fig. 3 illustrates multiple smart water sensors 1 each placed in a planter 150. Onboard microcontrollers 10a (controllers 10a) may be configured to wirelessly communicate with remote microcontroller 10b, and to identify each smart water sensor 1 (and planter 150) using sensor id 14 associated with the wireless transceiver 13 of each smart water sensor 1.

[023] As illustrated in Figs. 5, 6, 7, water detector 120 produces a detector signal 125 indicative of the water level relative to detector 120. Detector signal 125 may be a detector wet signal 125 indicative of water presence in plant reservoir 151 at the level 155 of water detector 120 and Detector signal 125 may be a detector dry signal 125 indicative of water absence at detector level 155 in plant reservoir 151. Water detector 120 may comprises an emitter 121 capable of emitting electromagnetic wave 122 (e.g. light in the visible or invisible spectra, other waves in the electromagnetic spectrum), a receiver 123 capable of producing detector signal 125, for example an electrical signal having voltage corresponding to incident wave energy 118 of electromagnetic wave 122 reflected portion 119 that is incident on, or is received at, receiver 123. Water detector 120 may also comprise a reflector 124 configured to reflect a portion 119 of electromagnetic wave 122 and redirect it to receiver 123. Reflector 124 comprises material selected and configured so that the reflected portion 119 varies depending on whether reflector 123 is immersed in air (indicating water absence) or is immersed in water (indicating water presence). In the figures air is represented with a 10% dotted pattern and water is represented with a horizontal lines pattern. The terms “water absence,” “not immersed in water,” and “immersed in air” are interchangeable and mean that the portion of reflector 124 on which electromagnetic wave 122 is received is entirely above the water level as illustrated in Fig. 5 for downward facing

water detector 120. Similarly, in such embodiments the terms “water presence,” and “immersed in water” are interchangeable and mean that the portion of reflector 124 on which electromagnetic wave 122 is received is entirely below the water level as illustrated in Fig. 5. For water detector 120 in which electromagnetic wave is emitted parallel to the water surface, the terms “immersed in water” and “not immersed in water” mean that emitter 121 is below the water surface.

[024] Fig. 7 illustrates an example of detector signal 125 voltages during a 28 hour period (1680 minutes) from bottom and top detector signals 125a, 125b depending on whether bottom and top detectors 125a, 125b are wet or dry. In this example, detector signal voltages above a 2.2V cutoff indicate a detector dry signal 125a, 125b due to a larger reflected portion 119a, 119b hitting receivers 123a, 123b resulting in a higher detector signal voltage. Signals below 2.2V indicate detector wet signal 125a, 125b. The detector signal voltages and the 2.2V voltage cutoff are exemplary and will depend on the configuration of detectors 125, the types of emitters 121, receivers 123, and reflectors 124, the wavelength and intensity of electromagnetic wave 122, and various other factors. Fig. 7, illustrates top detector dry-to-wet and wet-to-dry transition signals 128a, 128b. Top detector dry-to-wet transition signal 128b is top detector wet signal 125b (voltage, e.g., below 2.2V) preceded by a top detector dry signal 125b (e.g., above 2.2V). Water full timestamp 130 is the time stamp of the top detector dry-to-wet transition signal 128b. Top detector wet-to-dry transition signal 128a is a top detector dry signal 125b (e.g., above 2.2V) preceded by a top wet signal 125b and indicates that water in reservoir 151 has dropped below top water level 153, for example due to water consumption by plants in planter 150. Fig. 7 also illustrates a that bottom detector 120a stays wet (indicated by the series of bottom wet signals 125a below 2.2Va) until bottom detector 120a does not detect water at bottom water level 152 at bottom wet-to-dry transition signal 129a, being a bottom dry signal 125b preceded by a bottom wet signal 125b. Timestamp 16 of the bottom wet-to-dry transition signal 129a is the water consumed timestamp 131.

[025] Reflector 124 may comprise reflector material selected for its ability to exhibit different reflective and refractive properties depending on the medium (e.g., water, air) in which it is immersed, and on the angle of incident light or other electromagnetic wave. For example, reflector material may be selected, and the reflector configured (e.g., to provide a specific incidence angle of electromagnetic wave 122) so that reflector exhibits Total Internal Reflection (“TIR”) in air (i.e., water absence) but is at least partially

refractive, or only partially reflective, in water, so that a portion of the electromagnetic wave 122 is refracted into the water. Total Internal Reflection (TIR) is a phenomenon when an electromagnetic wave is completely reflected from the boundary between a denser material (e.g., transparent resin, glass, etc.) and a less dense material (e.g., air, water). TIR occurs when the electromagnetic waves hit the boundary between the two materials at an angle higher than a "critical angle," which can be calculated from the refractive indices of the two materials (denser material having a higher refractive index). If the electromagnetic wave hits the boundary at an angle smaller than the critical angle, part of the wave will be refracted, reducing the reflected portion of the wave. The refractive indices for various materials are generally known, and may depend on material density, incident wavelength, temperature, pressure, humidity, and other factors. As an example, an embodiment of the present invention, electromagnetic wave may be light, in the visible or Infrared spectrum, reflector material may be a transparent resin with a refractive index of approximately 1.5, air has a refractive index of approximately 1 (e.g., 1.00033) and water has an approximate refractive index of 1.33. Based on the refractive indices the critical angles can be calculated, and in this embodiment, the critical angle for the boundary between reflector 124 (resin) and air may be approximately 42 degrees (e.g., 41.81 degrees) and the critical angle for reflector 124 to water boundary may be approximately 62 degrees (e.g., 62.46 degrees). With that information, detector 120 can be configured so that electromagnetic wave 122 (e.g., light) will fall on reflector 124 at an angle (e.g., 45 degrees) that is larger than 42 degrees but smaller than 62 degrees (e.g., critical angles for reflector-air and reflector-water boundaries). In such configuration, when reflector 124 is surrounded by air (water absence) reflector 124 will exhibit TIR, reflecting substantially all (e.g., all or almost all) of electromagnetic wave 122 (e.g., light) towards receiver 123, and when surrounded by water reflector 124 will refract electromagnetic wave 122, reflecting only a reflected portion 119 to receiver 123. Other reflective materials such as glass, acrylic, IR transparent materials may be used for reflector 124, and other wavelengths may be utilized for electromagnetic wave 122, and detector 120 may be configured so that emitter 121 emits electromagnetic wave 122 to hit reflector 124 at appropriate angle so that reflector 124 will reflect substantially all of electromagnetic wave 122 when surrounded by air, and will reflecting none, or only a portion, of the electromagnetic wave when surrounded by water.

[026] Embodiment of detector housing 4 may comprise reflector material with the same properties as reflector 124 so that when the reflector material in the detector housing is positioned opposite emitter 121 and receiver 123, detector housing 4 may be configured to serve as reflector 123. Detector housing (e.g., comprising transparent resin with 1.5 refractive index) may be configured to act as reflector 123, for example, by configuring the detector housing walls so that electromagnetic wave 122 emitted by emitter 121 falls on the boundary between the detector housing wall and air or water at 45 degree angle.

[027] An embodiment of smart water sensor 1 comprises a bottom (first) water detector 120a and a top (second) water detector 120b. When smart water sensor 1 is placed in a planter water reservoir 151 bottom water detector 120a defines a bottom water level 152 and when power on is configured to detect water presence or water absence at the bottom water level 152. Top water detector 120b defines a top water level 153 within planter water reservoir 151 and is configured to detect water presence or water absence at the top water level 153.

[028] As illustrated in Fig. 6, bottom water detector 120a produces a bottom (or first) detector signal 125a based on (e.g., proportional to, function of) the reflected portion of bottom electromagnetic waves 122a emitted from bottom emitter 121a and received at bottom receiver 123a. Bottom detector 120a, preferably is positioned so that the bottom electromagnetic waves 122a are emitted by bottom emitter 121a downward towards bottom reflector 124a parallel to longitudinal axis 17 of detector housing 4. Such configuration enables the bottom reflector to be positioned almost flat, lying on the planter reservoir bottom 151a so that bottom water detector 124a will produce a bottom detector dry signal 125a only when substantially all water in the planter water reservoir 151 has been consumed. If bottom reflector 124a is positioned above the lowest point of the reservoir, an adjustment for the remaining water volume may be calculated based on the container geometry and the distance between the container bottom and the bottom detector.

[029] Top, or second, water detector 120 produces a top (or second) detector signal based on the reflection of top electromagnetic waves 122b emitted from top emitter 121b and reflected from a top reflector 124b.

[030] Embodiments of smart water sensor 1 are energy efficient and can preserve energy by spending most of the time in a low-powered sleep state and only waking up to acquire water level data, to transmit the data, and to pair with a target device. For example, microcontroller 10 can switch between a low-power state 55, a data

acquisition state 50, a transmission state 52, and a pairing state 54. Controller 10a of microcontroller 10 powers water detectors 120 and wireless transceiver 13 only when needed.

[031] While in data acquisition state 50, microcontroller 10 powers on top and bottom water detectors 120a, 120b to produce a top and bottom detector signal 1205a, 125b, indicative of water presence or absence at the top water level 153 and bottom water level 154. Microcontroller 10/controller 10a is configured to enter transmission state 52 after receiving top and bottom detector signals 125a, 125b.

[032] In the transmission state, which may last for a transmission duration 53, microcontroller 10 causes wireless transceiver 11 to continuously transmit a water sensor data packet, comprising water sensor Id 14, a target address 15, a timestamp 16, and the detector signals 125 (e.g., first detector signal 125a, and second detector signal 125b). In the low-power state, the microcontroller causes the first and second detectors and the wireless transceiver to be powered off, enters a sleep mode, and monitors for a wakeup signal.

[033] Microcontroller 10 enters the data acquisition state in response to receiving a data acquisition wakeup signal, which may be generated by RTC 13 periodically at the expiration of a regular data acquisition interval which may be pre-determined, or may be established and stored during pairing with a target device. Alternatively, the data acquisitions wakeup may be an external command received from a target device. Microcontroller 10 may switch from data acquisition state to transmission state after the microcontroller is finished receiving detector signals 125 from all water detectors 120. At the end of the transmission state, either due to the expiration of a transmission duration or receipt of an acknowledgement of successful transmission from the target device, the microcontroller enters the low-power state.

[034] In embodiments utilizing Bluetooth Low Energy (BLE) wireless communications, during the transmission state, the data packet may be a BLE advertising packet comprising water sensor identifier 14 (e.g., advertiser address, advertiser device name, UUID, and other relevant information), a target device address 15 (e.g., BLE intended recipient device id, payload data (e.g., detector signals), and other information.

[035] Smart water sensor 1 can be paired with a target device by entering the pairing state when it receives a pairing command. The pairing command may be a wakeup signal that is external, for example an electrical signal from a manual button 3, or a wireless command from a target device. Pairing state may also be entered if the smart

water sensor 1 enters data acquisition state if the smart water sensor is not paired to any target devices. During the pairing state, the wireless transceiver establishes a data link with the target device and stores the datalink information (for Bluetooth or BLE, e.g., smart water sensor and target device Bluetooth addresses, water sensor id 14, target address 15, Bluetooth keys, sync period). Smart water sensor 1 and remote microcontroller 10b and/or ILCU 6 (e.g., target device) may also share operational information such as data acquisition time period 51, transmission duration 53, and real time clock synchronization, and other data.

[036] The first and second detectors are located within detector housing 4. First detector 120a is located adjacent to or at the bottom end 4a, facing downward so that the first emitter 121a emits first electromagnetic wave 122a (e.g., light) downward, towards planter reservoir bottom 151a and bottom end 4a, parallel to longitudinal axis 17 of detector housing 4. First reflector 124a is configured to reflect the first light upward, away from bottom end 4a, parallel to longitudinal axis 17 of housing 4. Second emitter 121b emits the second electromagnetic wave 122b perpendicular to longitudinal axis 17 and the second reflector 124b reflects the second electromagnetic wave 122b towards second receiver 123b.

[037] Embodiments of smart water sensor 1 may comprise any quantity of water detectors (illustrated in Fig. 1 with five water detectors) each water detector configured to generate a detector signal indicative of water presence or absence at a detector water level. Detector wet and dry signals, detector wet-to-dry and dry-to-wet signal transitions, and their associated timestamps, may be used for determining rate of change of water level in reservoir 151, detect changes in environmental conditions over periods of time, detect problem with water delivery and water consumption, diagnose issues with plant health or soil moisture content; maintain a steady water level (e.g., for plant with roots that need to be immersed in water); allow precise water deliver (e.g., using variable rate pumps and reducing pump flow rates upon receiving wet signals from water detectors position near the top water level, and various other functions.

[038] Processing module 10ab may be configured to determine planter drink rate 20 representative of the water consumption by the plants in the planter over a period of time. While plants should be the main consumers of water and contributors to drink rate 20, other factors, such as evaporation, porosity of the planter, ambient temperature and humidity, and other factors, may also contribute to water consumption. By periodically receiving water detector signals 125 from smart water sensor 1, an irrigation

microcontroller may detect a dewatering duration 25 for a container. Dewatering duration 25 refers to the time for water volume 24 in the water reservoir to be consumed (e.g., by the plants, through evaporation, etc.). When bottom water detector 120 is positioned at or very near the bottom of the container, the consumed water volume 24 represents the entire water volume in the reservoir and dewatering duration 25 represents the time for substantially all water in the reservoir to be consumed. drink rate 20 can be calculated as the quotient of dividing the consumed water volume 24 by the dewatering duration 25.

[039] The consumed water volume 24 may be preset or may be determined based on the geometry or volume of the container, distance between top and bottom water detectors 120a, 120b, flowrate of water pumps and pumps run duration, and other methods. For example, an irrigation microcontroller may determine the water volume in a reservoir by multiplying a pump's flow rate by the pump on time until the pump turns off upon the top water detector 120 transmitting a detector wet signal 125. Intermediate water volumes 24a, b, c, between multimer detector water levels 155 illustrated in Fig. 1, may also be preset, or similarly determined. For example, in reservoir 151 container with known dimensions, water volume 24 when the top detector signal 125b turns from dry-to-wet may be determined by multiplying the distance between top and bottom detectors 125a, 125b by the area of reservoir bottom 151a. Such calculations may also be used to determine or confirm pump flowrates by dividing the water volume 24 by the pump on duration.

[040] To calculate water fill duration 26, or drink rate 20 microcontroller 10 may be configured to periodically initiate data acquisition to receive a bottom (or first) detector signal 125a, which may be a bottom detector wet signal 125a or a bottom detector dry signal 125a, and a top (or second) detector signal 125b, which may be a top detector wet signal 125b or top detector dry signal 125b. The periodic data acquisition may occur at a regular data acquisition interval 51. Each detector signal acquired at the regular data acquisition interval 51 is associated with timestamp 16 and added to a detector signal timeseries 126, enabling processing module 10b to identify a top detector transition signal 128 which may be a top detector wet-to-dry transition signal 128a (indicative of water level dropping below the top water level 153) and a top detector dry-to-wet transition signal 128b (indicative of water level rising to top water level 153). Top detector wet-to-dry transition signal 128a is a top detector dry signal 125b which is preceded in the timeseries 126 by a top detector wet signal 125b, and top detector

dry-to-wet transition signal 128b is a top detector wet signal 125b which is preceded in the timeseries 126 by a top detector dry signal 125b. Similarly, processing module 10b may be configured to identify a bottom detector transition signal 129 which may be a bottom detector wet-to-dry transition signal 129a (indicative of water level dropping below the bottom water level 153) and a bottom detector dry-to-wet transition signal 129b (indicative of water level rising to bottom water level 153). Bottom detector wet-to-dry transition signal 129a is a bottom detector dry signal 125a which is preceded in the timeseries 126 by a bottom detector wet signal 125a, and bottom detector dry-to-wet transition signal 129b is a bottom detector wet signal 125a which is preceded in the timeseries 126 by a bottom detector dry signal 125a.

[041] Timestamp 16 in timeseries 126 associated with bottom detector wet-to-dry transition signal 129a is a water consumed timestamp 131 indicating that water volume 24 has been consumed, and Timestamp 16 in timeseries 126 associated with top detector dry-to-wet transition signal 128b is a water full timestamp 130 indicating that water volume 24 has been delivered to reservoir 151. Processing module 10b may be configured to calculate dewatering duration 25 (or the time it takes for water volume 24 to be consumed) as the difference between water full timestamp 130 and water consumed timestamp 131. Processing module 10b may be configured to calculate reservoir water fill duration 26 (duration to deliver water volume 24 to reservoir 151) using timestamps 16 for top and bottom dry-to-wet transition signals 128b, 129b. Similarly processing module 10b may be configured to determine durations to consume or to deliver intermediate water volumes 24a, 24b, 24c by utilizing corresponding detectors wet-to-dry and dry-to-wet transition signals 127.

[042] Embodiments of the invention may be configured to calculate watering/irrigation period 100 to accommodate plants with different watering needs, different environmental conditions, and other factors. For example, an irrigation period 100 (IRP) for a planter may be determined based on planter drink rate 20 and watering parameters 21, using the formula:

$$IRP = M \times DR/ML$$

where ML is the moisture level 22, M is a multiple 23, and DR is planter drink rate 20. Moisture level (ML) 22 and multiple (M) 23 depend on the water requirements of the plants in the planter, the maximum desired period to let the soil dry after the reservoir is empty, and other factors.

[043] Multiple (M) 23 may be set as a constant in a particular embodiment, while ML 22 may vary between planters depending on the types of plants in each planter. In one example, multiple 23 may be set at 5,000,000 while ML 22 may be a number between a high and low limits for moisture level 22, where higher moisture levels 22 are assigned for plants requiring shorter dry outs between waterings and lower moisture levels 22 are assigned for plants that require less frequent waterings (i.e. longer dry out periods between watering). Moisture level 22 and multiple 23 could be determined experimentally, for example, by adjusting their values so that the low limit of moisture level 22 results in a desired dry out period compatible with the requirements of a particular dry loving plant, for example 5 days between watering for certain succulents. In the reverse, the watering parameters 21 values may be adjusted so that the limit of moisture level 22 results in a very short period between watering, e.g., a few hours, for plants whose roots should not dry out. A table (not shown) of moisture level (ML) 22 values for different plants may be stored in memory 11 associated with the microcontroller, and the system may be configured for a particular type of plant, which in turn may be matched to the appropriate watering parameters 21, such as moisture level 22 and multiple 23.

[044] Embodiments of ILCU 6 may be configured to deliver water to planter water reservoir 151 upon expiration of a dry period 101 following the consumption of water volume 24. Irrigation period 100 preferably is dry period 101, but other implementations are possible. For example, irrigation period 100 may be a drink-dry period 102 encompassing dewatering duration 25 and dry period 101 so that dry period 101 is determined as the difference between irrigation period 102 and dewatering duration 25, or irrigation period 100 may be a fill-dry period 103 encompassing water fill duration 26, dewatering duration 25 and dry period 101, so that dry period 101 is determined as the remainder of irrigation period 100 after subtracting the water fill duration 26 and dewatering duration 25.

[045] Embodiments of the invention may provide for an automated irrigation system for planters comprising an irrigation and light controller unit (ILCU) 6 and a smart water sensor 1 associated with a planter. ILCU 6 controls the lighting and watering schedules of a planter by powering on and off the lights and water pumps for planter 150. ILCU 6 manages water delivery to a planter by controlling water pumps associated with the planter based on the irrigation period 100. ILCU may comprise processing module 10b which receives water detector signals 125 from water detectors 120 through controller

10a (onboard microcontroller 10a) and wireless transceiver 12 and is configured to calculate planter drink rate 20 and planter irrigation period 100 as described above. Alternatively, ILCU may receive planter irrigation 100 from microcontroller 10 in embodiments in which processing module 10b is located onboard of smart water sensor 1.

[046] ILCU 6 may comprise irrigation microcontroller 10b and one or more wireless transceivers capable of BLE and/or Wi Fi communication. ILCU 6 may also comprise one or more pump control outputs. Wireless communication, preferably Wi Fi, may be used to connect to a cloud network and a server for system settings synchronization, for uploading of logs and other data, and for remote device management. Wireless communications, preferably BLE, can be used to allow the processing module 10b and/or ILCU 6 to connect with a mobile app 7 for managing settings, viewing timeseries 126 and logs, to pair processing module 10b and/or ILCU 6 with smart water sensors and to acquire water sensor data. Control outputs for water pumps may be hardwired, or may be wireless so that ILCU 6 is able to turn pumps on and off wirelessly.

[047] Processing module 10b may pair with a plurality of smart water sensors 1, each sensor inserted in (and, e.g., associated with) a planter 150. When paired with processing module 10b each smart water sensor 1 may transfer sensor data (e.g., including water detector signals, water sensor id) related to the plants in its associated planter 150.

[048] Based on irrigation period 100 and water sensor data, the ILCU 6 may implement an automatic irrigation schedule for planters. For example, ILCU 6 may utilize, from processing module 10b (either local to smart water sensor 1, or within ILCU 6), bottom water detector wet and dry signals 125a, top water detector wet/dry signals 125b, and irrigation period 100 for a planter 150 to generate an automated irrigation schedule to the planter 150. In an automated irrigation schedule, upon the expiration of the irrigation period 100 while the bottom water detector is dry (indicated by a bottom detector dry signal 125a), ILCU 6 may energize a pump control output (not shown) associated with planter 150 to turn on planter water delivery pump (not shown), and may also start an overflow timer (not shown) simultaneously with energizing pump control output. ILCU 6 may turn off/de energize the pump control output when top water detector 120b transitions from dry-to-wet (indicated by a top detector dry-to-wet transition signal 129b) or upon expiration of the overflow timer, whichever occurs first. ILCU 6 may also cause controller 10a or processing module 10b to cause periodic data acquisitions at a regular

data acquisition interval 51 and periodic calculation of planter drink rate 20 and planter irrigation period 100 to adjust the automated irrigation schedule based on dynamic learning of how planter drink rate 20 varies with time.

[049] When setting up a new planter 150, or if planter 150 is dried out (e.g., upon identifying a low /zero drink rate, described below), ILCU 6 may be configured to execute a planter water flush to saturate the soil. ILCU 6 may activate the water pump delivery to the planter until a flush detector 120c detects water presence at the flush detector water level, indicated for example by processing module 10b identifying a signal indicating a transition from dry-to-wet at the flush detector dry-to-wet signal transition. ILCU 6 may also initiate removal of excess water from planter water reservoir 151 (by, e.g., reversing the water delivery pump, activating a water removal pump). Removal of excess water stops based on one or more of the pump run duration to remove water, the flow rate of water removal (reversed pump, water removal pump), and water detector signals 125. The volume of excess water that needs to be removed may be configurable, for example, set as a predefined volume, or it could be the volume of water contained between any two water detectors. Such flexibility may enable precise control over the water flush process.

[050] Processing module 10b and/or ILCU 6 may also be configured to identify low or non-existing planter drink rate 20 which may indicate that the plants in planter 150 are not successfully receiving moisture from reservoir 150. In embodiments of smart water sensor 1 comprising one or more intermediate water detectors 120 positioned between bottom water detector 10a and top water detector 120b (e.g., illustrated in Fig. 1) low/zero drink rate 20 may be detected if water detectors 120 do not detect a reduction of water level for a period of time during which a reduction of water level would be expected. Alternatively, processing module 10b may calculate intermediate drink rates 20a based on timestamped detector signals 125, 125a, 125b from the top, bottom, and the one or more intermediate water detectors 120, 120a, 120b, and water volumes 24a, b, c, contained between water detectors water levels 153, 152, 155. In embodiments with only a top and bottom water detectors 120a, 120b, low/zero planter drink rate may be detected when processing module 10b calculates the planter drink rate 10.

[051] ILCU 6 may also be configured to operate independently of smart water sensors 1, and to operate the pump control outputs based on preset scheduled irrigation timers, one shot manual timers, and manual pushbutton activation. Scheduled irrigation timers can be set to repeat on a specific schedule at certain time and run for a certain Manual

pump timers allow a user to run the pumps outside of their regular schedule by starting timers to immediately activate the pump for the timer duration. Manual timers and pushbutton activation may be useful if the planters need a quick boost of water or if there are issues with the smart sensors.

[052] While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes, omissions, and/or additions may be made and equivalents may be substituted for elements thereof without departing from the spirit and scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, unless specifically stated any use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another.

We claim:

1. A smart water sensor for monitoring water consumption in a planter, the smart water sensor comprising:
 - a microcontroller comprising a controller and a processing module;
 - a detector housing having a bottom end;
 - a top water detector; and,
 - a bottom water detector placed within the detector housing at the bottom end;wherein the microcontroller is associated with a memory, the memory configured to store watering parameters;
- wherein the watering parameters comprise information representative of water requirements and a water delivery system for the planter;
- wherein the smart water sensor is configured to be placed in a planter water reservoir with the bottom end in proximity to a planter reservoir bottom;
- wherein the top water detector defines a top water level of a water volume in the planter water reservoir;
- wherein the bottom water detector defines a bottom water level of the water volume in the planter water reservoir;
- wherein the top water detector is configured to:
 - detect water presence and water absence at the top water level; and,
 - produce a top detector wet signal indicative of water presence at the top water level;
- wherein the bottom water detector is configured to:
 - detect water absence and water presence at the bottom water level; and,
 - produce a bottom detector dry signal indicative of water absence at the bottom water level; and,
- wherein the microcontroller is configured to:
 - receive the top detector wet signal and the bottom detector dry signal;
 - determine a water full timestamp associated with the top detector wet signal; and,
 - determine a water consumed timestamp associated with the bottom detector dry signal;
 - calculate a dewatering duration as a function of a time elapsed between the water full timestamp and the water consumed timestamp; and,
 - calculate a planter drink rate as a ratio of a predetermined volume of water and the dewatering duration.

2. The smart water sensor of claim 1,
wherein the top water detector is further configured to produce a top detector signal
indicative of water presence or water absence at the top water level;
wherein the top detector signal is one of the top detector wet signal or a top detector dry
signal;
wherein the top detector dry signal is indicative of water absence at the top water level;
wherein the bottom water detector is further configured to produce a bottom detector
signal indicative of water presence or water absence at the bottom water level;
wherein the bottom detector signal is one of a bottom detector wet signal or the bottom
detector dry signal;
wherein the bottom detector wet signal is indicative of water presence at the bottom
water level;
wherein the controller is configured, at a regular data acquisition interval, to:
cause the top water detector to produce the top detector signal and the bottom
water detector to produce the bottom detector signal;
wherein the processing module is configured to:
receive the top detector signal and the bottom detector signal;
associate the bottom detector signal and the top detector signal with a
timestamp; and,
add the timestamp, the top detector signal, and the bottom detector signal to a
detector signal timeseries;
wherein responsive to receiving the top detector signal and the bottom detector signal,
the processing module is configured to:
identify one of a top detector dry-to-wet transition signal, a bottom detector
wet-to-dry transition signal, or combinations thereof;
determine the water full timestamp as a timestamp associated with the top
detector dry-to-wet transition signal; and,
determine the water consumed timestamp as a timestamp associated with the
bottom detector wet-to-dry transition signal;
wherein the top detector dry-to-wet transition signal is the top detector wet signal
preceded in the detector signal timeseries by the top detector dry signal; and,
wherein the bottom detector wet-to-dry transition signal is the bottom detector dry signal
preceded in the detector signal timeseries by the bottom detector wet signal.
3. The smart water sensor of claim 2, wherein the bottom water detector comprises a

bottom emitter, a bottom reflector, and a bottom receiver;
wherein the bottom emitter, the bottom reflector, and the bottom receiver are configured so that a bottom electromagnetic wave emitted by the bottom emitter is reflected from the bottom reflector and is received at the bottom receiver; wherein the bottom water detector is placed within the detector housing so that the bottom emitter emits the bottom electromagnetic wave downward towards the planter reservoir bottom;
wherein the bottom receiver is configured to produce the bottom detector signal representative of a bottom reflected portion of the bottom electromagnetic wave received at the bottom receiver;
wherein the bottom detector signal is the bottom detector dry signal when the bottom reflector is not immersed in water and is the bottom detector wet signal when the bottom reflector is immersed in water;
wherein the top water detector comprises a top emitter, a top reflector, and a top receiver;
wherein the top detector is positioned within the detector housing so that the top emitter emits a top electromagnetic wave perpendicular to the longitudinal axis of the detector housing;
wherein the top receiver is configured to produce the top detector signal representative of a top reflected portion of the top electromagnetic wave received at the top receiver;
wherein the top detector signal is the top detector dry signal when the top detector is not immersed in water and is the top detector wet signal when the top detector is immersed in water, and,
wherein the bottom reflected portion is a bottom dry reflected portion and a bottom wet reflected portion;
wherein the top reflected portion is a top dry reflected portion and a top wet reflected portion;
wherein the top reflector when immersed in air is configured to reflect the top dry reflected portion of the top electromagnetic waves;
wherein the bottom reflector when immersed in air is configured to reflect the bottom dry reflected portion of the bottom electromagnetic waves;
wherein the top reflector when immersed in water is configured to reflect the top wet reflected portion of the top electromagnetic waves;

wherein the bottom reflector when immersed in water is configured to reflect the bottom wet reflected portion of bottom electromagnetic waves;

wherein the bottom dry reflected portion is sufficiently different from the bottom wet reflected portion so that the top detector dry signal is detectably different from the top detector wet signal and the bottom detector dry signal is detectably different from the bottom detector wet signal; and,

wherein the top dry reflected portion is different from the top wet reflected portion so that the top detector dry signal is detectably different from the top detector wet signal and the bottom detector dry signal is detectably different from the bottom detector wet signal.

4. The smart water sensor of claim 3, wherein the detector housing comprises reflector material opposite each of the top emitter and the bottom emitter;

wherein the detector housing is configured so that the reflector material is totally internally reflective when immersed in air, and is partially refractive when immersed in water;

wherein the reflector material opposite the top emitter is the top reflector; and,

wherein the reflector material opposite the bottom emitter is the bottom reflector.

5. The smart water sensor of claim 4, wherein the controller is configured to cause the smart water sensor to be in one of a low-power state or a data acquisition state;

wherein in the data acquisition state the controller is configured to:

- power on the top water detector to produce the top detector signal;
- power on the bottom water detector to produce the bottom detector signal; and,
- receive the top detector signal and the bottom detector signal;

wherein the responsive to receiving the top detector signal and the bottom detector signal, the controller is configured to cause the smart water sensor to enter the low-power state;

wherein in the low-power state the controller is configured to:

- power off the top water detector and the bottom water detector;
- monitor for a data acquisition command; and,
- receive the data acquisition command;

wherein responsive to receiving the data acquisition command the controller is configured to enter the data acquisition state;

wherein the processing module is further configured to calculate an irrigation period as a function of the planter drink rate and the watering parameters; and,

wherein the irrigation period is one of a dry period, a drink-dry period, or a fill-dry period.

6. The smart water sensor of claim 5, wherein the watering parameters comprise a moisture level and a planter watering multiple;

wherein the moisture level is a value indicative of water requirements of the planter based on plant types;

wherein the planter watering multiple is a predetermined value based on one or more of a watering delivery system for the planter, characteristics of the planter, and environmental conditions of the planter; and,

wherein the processing module is further configured to calculate an irrigation period as a product of the plater watering multiple and the planter drink rate divided by the moisture level.

7. The smart water sensor of claim 5, further comprising:

a wireless transceiver associated with a water sensor id;

wherein the microcontroller comprises an onboard microcontroller comprising the controller and a remote microcontroller comprising the processing module;

wherein the onboard microcontroller is placed in the detector housing;

wherein the onboard microcontroller and the remote microcontroller are configured to communicate wirelessly through the wireless transceiver;

wherein the controller is further configured to cause the smart water sensor to be in one of the low-power state, the data acquisition state, a transmission state, or a pairing state;

wherein in the data acquisition state responsive to receiving the top detector signal and the bottom detector signal, the controller is configured to cause the smart water sensor to be in the transmission state for a transmission duration;

wherein in the transmission state the controller is configured to:

power on the wireless transceiver;

cause the wireless transmitter to transmit a water sensor data packet comprising the water sensor id, a target address, the top detector signal, and the bottom detector signal;

wherein responsive to the expiration of the transmission duration, the controller is configured to enter the low-power state;

wherein in the low-power state the controller is further configured to:

power off the wireless transceiver; and,

monitor for a wakeup command;

- wherein the wakeup command is one of the data acquisition command or a pairing command;
- wherein responsive to receiving the pairing command, the controller is configured to cause the smart water sensor to transition to the pairing state;
- wherein in the pairing state, the controller is configured to utilize the wireless transceiver to establish a datalink with the remote microcontroller;
- wherein the target address is associated with the remote microcontroller;
- wherein during the pairing state, the controller stores in the memory one of datalink information, the regular data acquisition interval, the transmission duration, or combinations thereof;
- wherein the datalink information comprises the target address;
- wherein the pairing command is one of a local pairing command or a remote pairing command;
- wherein the local pairing command is generated responsive to activating a pairing control positioned on the detector housing; and,
- wherein the remote microcontroller is configured to transmit the remote pairing command.
8. The smart water sensor of claim 7, wherein the remote microcontroller is configured to receive the water sensor data packet;
- wherein the processing module is configured to receive the top detector signal and the bottom detector signal; and,
- wherein the detector signal time series is associated with the water sensor id.
9. The smart water sensor of claim 8, wherein the remote microcontroller is further configured to transmit the data acquisition command at the regular data acquisition interval.
10. The smart water sensor of claim 8, further comprising a real time clock;
- wherein the real time clock is configured to generate the data acquisition command at the regular data acquisition interval.
11. A smart water sensor for monitoring water consumption in a planter, the smart water sensor comprising:
- a detector housing comprising a detector housing bottom end;
- a microcontroller;
- a memory;
- a first water detector having a first detector bottom;

a second water detector; and,
a wireless transceiver associated with a water sensor id;
wherein the microcontroller is electrically connected with the first water detector and the second water detector;
wherein the microcontroller, the first water detector, the second water detector, and the wireless transceiver are located within the detector housing;
wherein the microcontroller is configured to receive a first detector signal from the first water detector and a second detector signal from the second water detector;
wherein the first detector bottom is located at the detector housing bottom end;
wherein when powered on, the first water detector is configured to produce the first detector signal indicative of water presence or water absence relative to the first detector bottom;
wherein the first detector signal is a first detector dry signal indicative of water absence at the first detector bottom;
wherein the first detector signal is a first detector wet signal indicative of water presence at the first detector bottom;
wherein when powered on, the second water detector is configured to produce a second detector signal indicative of water presence or water absence relative to the second water detector;
wherein the second detector signal is a second detector dry signal indicative of water absence at the second water detector;
wherein the second detector signal is a second detector wet signal indicative of water presence at the second water detector;
wherein the microcontroller is configured to be in one of a low-power state, a data acquisition state, a transmission state, or a pairing state;
wherein in the data acquisition state, the microcontroller is configured to:
power on the first water detector and the second water detector;
receive the first detector signal and the second detector signal;
wherein in the transmission state, for a transmission duration, the microcontroller is configured to cause the wireless transceiver to transmit a water sensor data packet comprising the water sensor id, a target address, the first detector signal, and the second detector signal;
wherein the microcontroller is configured to:
power off the first water detector and the second water detector during the

low-power state and during the transmission state;
power off the wireless transceiver during the low-power state and during the data acquisition state;
power on the wireless transceiver during the transmission state and during the pairing state; and,
wherein during the low-power state, the microcontroller and the wireless transceiver are configured to monitor for a wakeup command and receive the wakeup command;
wherein the wakeup command is one of a data acquisition command or a pairing command;
wherein the pairing command is one of a local pairing command or a remote pairing command;
wherein the local pairing command is generated responsive to activating a pairing control positioned on the detector housing;
wherein a target device transmits the remote pairing command;
wherein responsive to receiving the data acquisition command, the microcontroller is configured to enter the data acquisition state;
wherein responsive to receiving the first detector signal and second detector signal in the data acquisition state, the microcontroller is configured to enter the transmission state;
wherein responsive to the expiration of the transmission duration, the microcontroller is configured to enter the low-power state;
wherein responsive to receiving the pairing command, the microcontroller is configured to enter the pairing state;
wherein during the pairing state, the wireless transceiver is configured to establish a datalink with the target device;
wherein the target device is associated with the target address;
wherein during the pairing state, the wireless microcontroller stores in the memory one of a datalink information, a regular data acquisition interval, the transmission duration, or combinations thereof; and,
wherein the datalink information comprises the target address.

12. The smart water sensor of claim 11,
wherein the first water detector comprises a first emitter, a first reflector, and a first receiver; and,
wherein the first detector bottom comprises the first reflector;

wherein the first emitter, the first reflector, and the first receiver are configured so that a first electromagnetic wave emitted by the first emitter is reflected from the first reflector and is received at the first receiver;

wherein the first receiver is configured to produce the first detector signal representative of a first wave energy of a first incident wave energy received at the first receiver;

wherein the second water detector comprises a second emitter, a second reflector, and a second receiver;

wherein the second emitter, the second reflector, and the second receiver are configured so that a second electromagnetic wave emitted by the second emitter is reflected from the second reflector and is received at the second receiver;

wherein the second receiver is configured to produce the second detector signal representative of a second incident wave energy received at the second receiver;

wherein the first incident wave energy is proportional to a first incident electromagnetic wave reflected by the first reflector and received at the first receiver;

wherein the second incident wave energy is proportional to a second incident electromagnetic wave reflected by the second reflector and received at the second receiver;

wherein the first reflector and the second reflector when surrounded by air are configured to:

- be totally internally reflective;
- reflect substantially all of the first electromagnetic wave as the first incident electromagnetic wave;
- reflect substantially all of the second electromagnetic wave as the second incident electromagnetic wave;
- cause the first receiver to produce the first detector dry signal; and,
- cause the second receiver to produce the second detector dry signal; and,

wherein the first reflector and the second reflector when surrounded by water are configured to:

- be partially refractive;
- reflect a portion of the first electromagnetic wave as the first incident electromagnetic wave;
- reflect a portion of the second electromagnetic wave as the second incident electromagnetic wave;
- cause the first receiver to produce the first detector wet signal; and,

cause the second receiver to produce the second detector wet signal.

13. The smart water sensor of claim 12,
wherein the microcontroller and the wireless transceiver are configured to receive the
data acquisition command at the regular data acquisition interval;
wherein the data acquisition command is a local data acquisition command or a remote
data acquisition command;
wherein the microcontroller is configured to use the wireless transceiver to receive the
remote data acquisition command from the target device;
wherein the microcontroller is configured to receive the local data acquisition command
from a real time clock; and,
wherein the real time clock is configured to:
access the regular data acquisition interval from the memory; and,
generate the local data acquisition command at the regular data acquisition
interval.

14. The smart water sensor of claim 13, wherein the first emitter is positioned to emit the
first electromagnetic wave downward and parallel to a longitudinal axis of the
detector housing;
wherein the first reflector is positioned to reflect the incident first electromagnetic wave
parallel to the longitudinal axis of the detector housing towards the first receiver;
and,
wherein the second detector is positioned within the detector housing so that the second
emitter emits the second electromagnetic wave perpendicular to the longitudinal
axis of the detector housing, and the second reflector reflects the second
electromagnetic wave perpendicular to the longitudinal axis of the detector
housing towards the second receiver.

15. The smart water sensor of claim 14, wherein the first reflector comprises two first
reflector surfaces positioned perpendicular to each other;
wherein the first water detector is positioned so that the two first reflector surfaces form
a 45 degree angle with the longitudinal axis of the detector housing;
wherein the second reflector comprises two second reflector surfaces positioned
perpendicular to each other; and,
wherein the second detector is positioned so that the two second reflector surfaces form
a 45 degree angle with the axial axis of the detector housing.

16. The smart water sensor of claim 15, wherein the detector housing comprises

reflector material opposite each of the first emitter and the second emitter;
wherein the detector housing is configured so that the reflector material is totally
internally reflective when surrounded by air, and is a partially refractive when
surrounded by water;

wherein the reflector material opposite the top emitter is the second reflector; and,
wherein the reflector material opposite the bottom emitter is the first reflector.

17. The smart water sensor of claim 15, wherein the first emitter is a first light emitting
diode, the first receiver is a first photo diode, and the first electromagnetic wave is
a first light; and,

wherein the second emitter is a second light emitting diode, the second receiver is a
second photo diode, and the second electromagnetic wave is a second light.