A passive water transfer/retention system for long term functionality of an on-site sensing device

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Abstract

We proposed a passive water transfer/retention system for a device such as a sensor electrode for long-term functionality. This design aims to provide water to a device/material in order to keep the device/material in a wet condition for a long time using a small amount of water in the reservoir. Our design does not need any active sensor, pump, or valve to control the water refilling. This design can be used for the application such as on-site monitoring of the soil nutrients.

Keywords—water retention, water transfer, passive system

I. INTRODUCTION

There is a need to keep the devices or materials moist for a long time [1]. For example, the pH electrodes need to be stored in buffer solution when not used [2]. Usually, this can be achieved if the devices or materials can be stored in an enclosure or do not need to be always exposed to air (there is minimum evaporation). However, for some situations, the device or materials need to be exposed to an ambient environment. The evaporation of the water will require constant refilling of the water or moisture.

Traditionally, monitoring soil means going out to the field, taking soil samples, processing and doing measurements, and comparing to existing knowledge of the soil. The development of technology today makes it possible to remotely track the soil parameters, such as moisture, temperature, pH, salinity, and so on, with much higher accuracy [3]. For the soil nutrition monitoring in the farm, ion concentration needs to be monitored for a long time or sampled many times. A device that can function continuously without a sample preparation process will be beneficial in such a case. It is also essential to keep the sensor surface wet and enable the target ions to be transferred and detected anytime.

In this paper, a water transfer/retention system and a packaging method are used to keep the device functioning for a long time without drying out. The key components are a self-adjustable fluidic reservoir and fluidic channel with water retention materials to keep the surrounding of the sensing electrodes wet.

For on-site soil monitoring, the soil needs to contact sensing electrodes or gel materials that cover the electrodes. The ions in the soil should be able to diffuse onto the electrodes and transfer to an electrical signal, which means the electrodes need to be wet and, at the same time, exposed to the surrounding environment. Depends on the humidity and the temperature, the water inside this volume will evaporate over time. If no water is refilled into this volume, the sensor will be dried out and cannot function properly. A water reservoir can be connected to the device/material through a fluidic channel to refill the sensor only when necessary.

Conventionally there are a few methods to enable water refilling: One approach is to attach a humidity/moisture sensor to the ion sensor electrode, and a valve to the fluidic channel [4,5]. Whenever the humidity is lower than a threshold level, the valve can be triggered to open, and a certain amount of water can be delivered to the ion sensor. This approach is similar to the closed-loop controlled irrigation system [6]. The system of such an approach is complicated, and the cost is high. The second approach is an open-loop controlled system, where a timer is used to open the valve for the water refilling. This method removes the sensor and makes the system cheap and less complicated [7].

For both of the above approaches, a battery is needed to control the mechanic valve. This will increase the cost and also usually the water volume needed in the reservoir is large. It is also possible to use the capillary force to wick the water to the device to keep the humidity. However, it is difficult to use a small amount of water, and also, the clogging issue[8] of the microfluidics channel makes it difficult to use it in a harsh environment for a long time.

II. METHODS

We proposed using hydrophilic materials, such as a hydrogel or other water absorbent gels [9,10] to form a chamber surrounding the ion sensor electrode. Part of this chamber is exposed to the environment where ions to be detected can diffuse onto the sensor electrode (Fig. 1). By connecting this chamber to a water reservoir, it will consume water from the reservoir to ensure the moisture inside the chamber whenever the water is evaporated. Evaporation rate depends on the

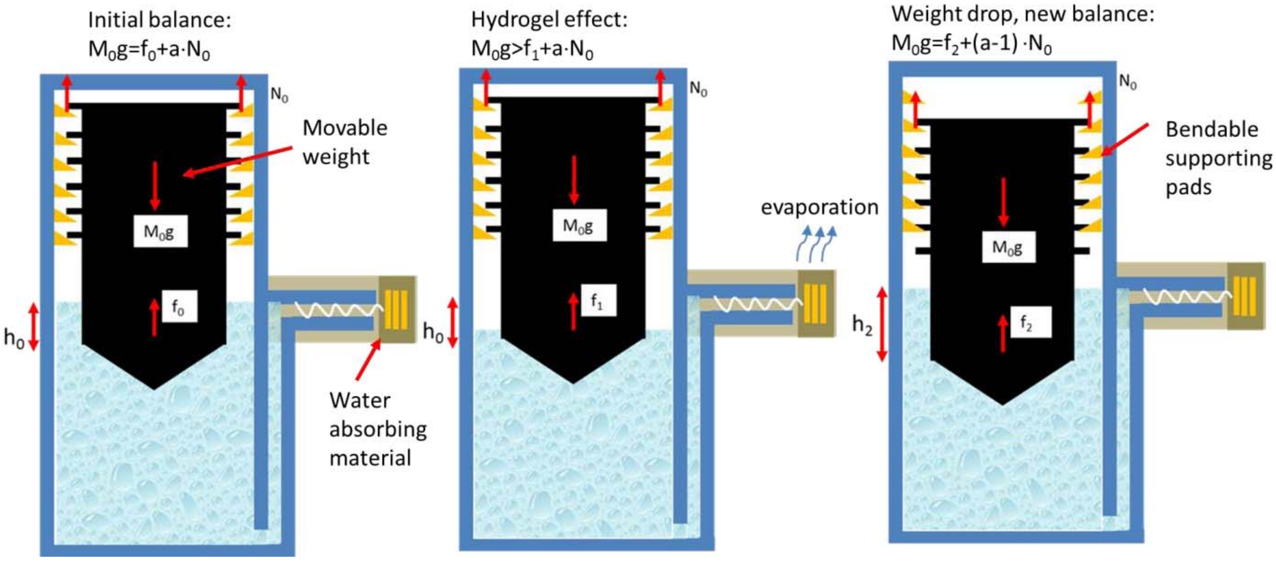

Fig. 1. The working mechanism of the proposed water transfer system (a=6 in the schematic as one example). Water absorbing material is used to keep the device wet and can also pump water from the reservoir. Movable weight (M_0), balanced by floating force and supporting force from a series of bendable pads, can prevent water level inside the reservoir from decreasing too much. Hydrogel will pump water from the reservoir due to water lost through evaporation. When the water level is too low to support the weight, the weight will drop and increase the water level so that the floating force will increase to reach a new balance.

temperature, exposed area size, and humidity of the environment. The water-absorbent material will only withdraw enough water to keep the moisture; thus the water consumption is small.

But when the water reservoir level is far below the hydrogel level, the hydrogel's withdraw force is not large enough to pump water to the device. In order to keep pumping water to the device, we designed a self-adjustable reservoir with a movable weight supported by both floating force and supporting force from the flexible pads (Fig. 1).

At the initial state, the water level inside the reservoir is the same as the hydrogel. The weight (M_0g) is balanced by the floating force (f_0) of the water and the force of 6 (as one example) sets of flexible supporting pads ($6\times N_0$).

When the water evaporates through the exposed hydrogel, the water from the reservoir will be pumped out; thus the water level inside the reservoir decreases and thus, decreases the floating force on the weight.

When the floating forced decreased to a certain level that the pads themselves ($6\times N_0$) cannot balance the weight and it will fall, thus push up the water level inside the reservoir, this will increase the water level and the floating force (f_1). This floating force is bigger than the initial one (f_0), but the supporting force from the pads is changed to only $5\times N_0$, so it can still balance with the weight (M_0g).

The above process can be repeated when water is pumped out and evaporated from the hydrogel when the weight falls down step by step. Most of the water inside the reservoir can be pushed out step by step at a low pumping rate. The merit of such a design is that the flow rate depends on the pumping or evaporation rate of the exposed hydrogel only, which can be controlled by design.

III. EXPERIMENT AND RESULTS

Fig. 2 is one example of the sensor integrated with a water reservoir. Sensor electrodes are covered with hydrogel, and a fluidic channel with water is connected to the hydrogel (Fig. 2d). The hydrogel is exposed to the environment and ions can diffuse onto the electrode and water can evaporate.

Conductivity measurement was done to evaluate the water retention effect of the hydrogel using the above setup. A chip with two Au electrodes was put under the fluidics chamber. When no water is inside the chamber, the resistance is high (larger than 100 kΩ at 1 kHz). When a KCl solution (10 mM) is introduced into the chamber, the resistance is below 5 kΩ at 1 kHz (Fig. 3). For the chip without adding hydrogel, the resistance increase with buffer evaporation. The resistance increased to above 100 kΩ (1 kHz) after around one day when the solution on top of electrodes is dried out, which shows a loss of the functionality of the device. For the device with hydrogel injected into the chamber above the sensor electrodes. There is no dramatic resistance change after testing for three days, where 500 μl of KCl solution is used in the reservoir. The results demonstrated the moisture retention capability of the hydrogel.

Fig. 4(a) to 4(f) demonstrated water retention testing with the above device. Fig. 4(1) to 4(6) are the corresponding schematic of the cross-section of the experiment. KCl solution (10 mM) with green dye is injected into the fluidic chamber, a small area (2 mm × 2 mm) is exposed to the air.

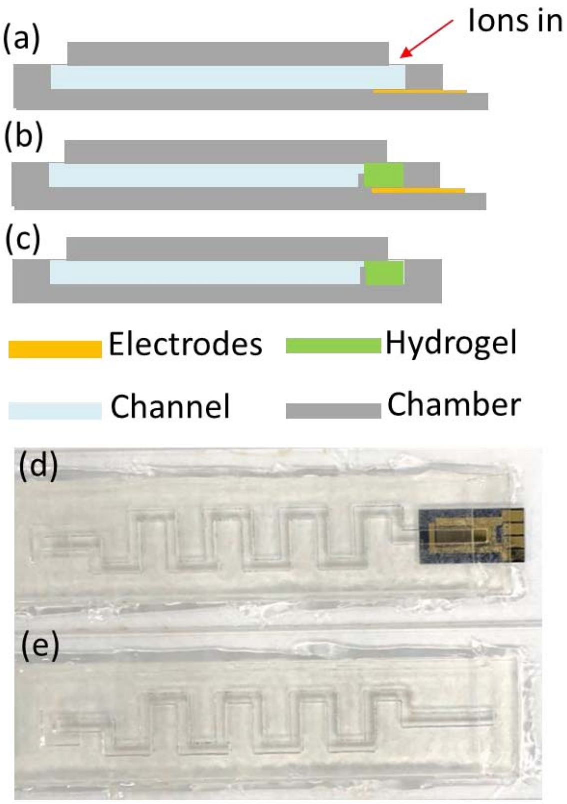

Fig. 2. (a) Cross-section of the schematic of an ion-sensor chip with a water reservoir. Ions can dissolve into the electrodes through an opening. (b) The hydrogel is used to seal the chamber, lock the water and keep the humidity of the sensor electrodes. (c) Cross-section schematic of testing fluidics for water retention experiment. (d) A sensor chip integrated with a fluidics reservoir. (e) A testing fluidics chamber for water retention experiment without the sensor chip.

When no hydrogel is introduced, the water will evaporate slowly, and the exposed area will be dried out in around one day (d/4, e/5, f/6). This phenomenon is not affected by the solution volume inside the fluidics chamber, which means adding more water inside the reservoir does not decrease the rate of drying as it always happened in the exposed area. When a small amount of hydrogel is put inside the open area of the fluidic chamber (a/1), water will evaporate the same way. But once evaporation happened, the hydrogel will withdraw more water from the fluidic channel (b/2, c/3). 500 µl of KCl solution will last for more than 5 days at ambient conditions. A larger volume of water inside the chamber will last a longer time. Assume the same situation, 40 ml of water will last more than one year.

Due to the hydrogel's water-absorbent characteristics, water can be pumped up at a level lower than the hydrogel. Fig. 5 demonstrated three fluidics channels, which have different initial water levels compared to the hydrogel. The initial reservoir level is 35 mm below hydrogel for channel 1; the initial reservoir level is 25 mm below hydrogel for channel 2; the initial reservoir level is 15 mm below hydrogel for channel 3. The hydrogel can withdraw water from the reservoir for both channel 2 and 3, but not channel 1. In order to continuously pump the water from the reservoir, there is a need to restore the water level inside the reservoir. This is realized by the self-adjustable reservoir described before, which uses a weight and flexible pads to push the water out slowly and at the same time to keep the water level inside the reservoir to be similar to the hydrogel height.

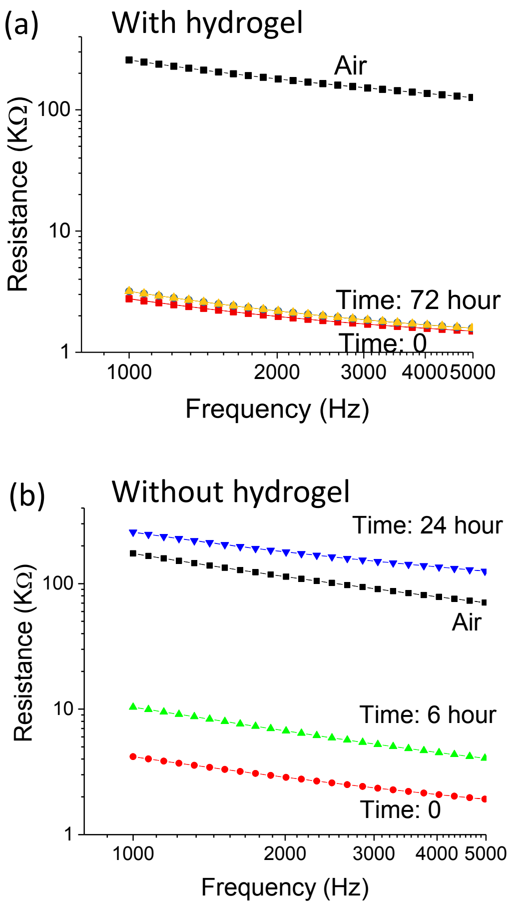

Fig. 3. Conductivity measurements of the sensing electrodes with (Fig. 2d) and without hydrogel (Fig. 2e) sealing. The device was dried out when no hydrogel was used after around one day, and the device with hydrogel shows a negligible change of conductivity after three days when 500 µL of KCl solution was used in the water reservoir.

Different embodiments can be used for the design of the self-adjustable weight. The flexible pads can be set on the chamber (Fig. 6a) or the movable weight (Fig. 6b). the second embodiment is useful for the design of the chamber with a small form factor. A miniaturized water retention system prototype was fabricated out with the cross section to be 34mm×31mm

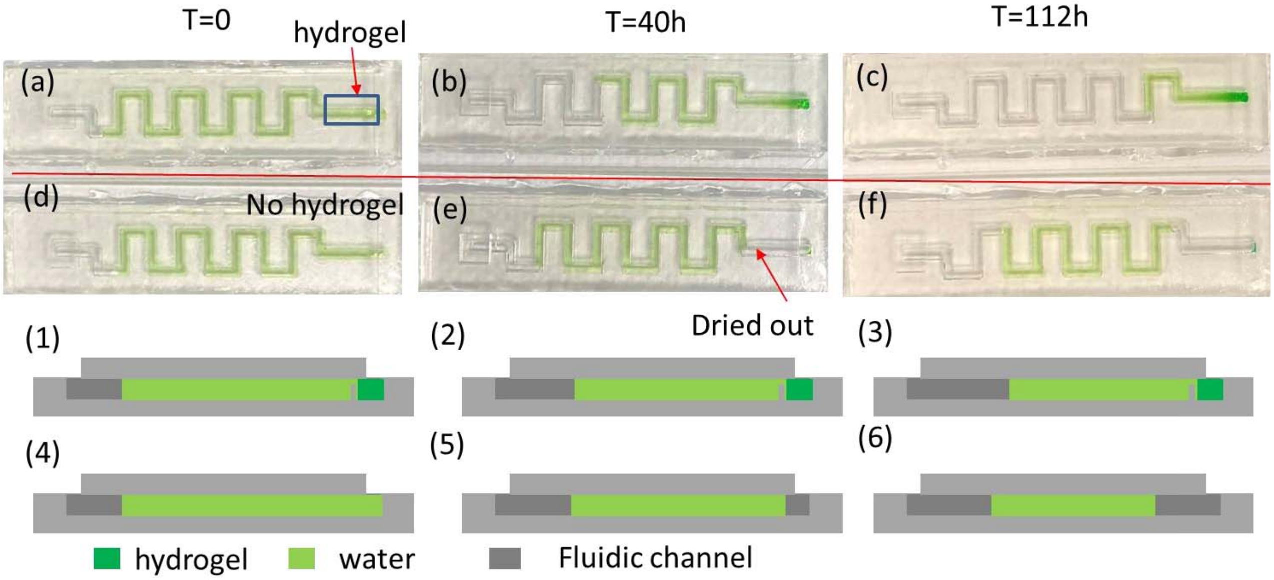

Fig. 4(a) to 4(f) demonstrated the water retention testing experiment. Fig. 4(1) to 4(6) are the corresponding schematic of the cross-section of the experiment. 500 µl of KCl solution with green dye is injected into the fluidics chamber with (a, b, c) and without hydrogel (d, e, f) sealing the chamber. The open area dried in around one day when no hydrogel is used for sealing. The KCl solution was slowly withdrawn to the open area for five days.

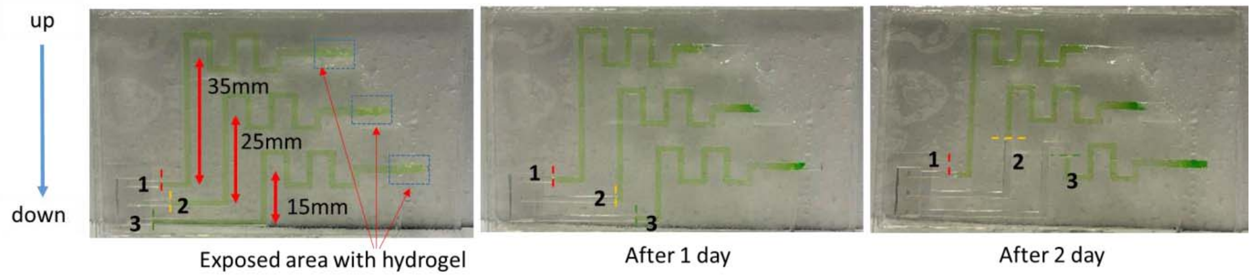

Fig. 5. Three fluidics channels demonstrate the capability of the hydrogel to withdraw water from the reservoir below. The initial reservoir level is 35 mm below hydrogel for channel 1; the initial reservoir level is 25 mm below hydrogel for channel 2; the initial reservoir level is 15 mm below hydrogel for channel 3. The hydrogel can withdraw water from the reservoir for both channel 2 and 3, but not channel 1.

and height of 100mm (Fig. 7). the volume of the water in the reservoir to be around 9 mL, and the estimation of the time it can last is around 2-3 months. A speeding test is done by replacing the hydrogel using a tube to transfer the water in supporting video (supporting information). It clearly shows that the weight of mass can be used to transfer the water to ensure the outlet wettability continuously.

IV. SUMMARY

In conclusion, we have demonstrated a simple, passive method to realize water retention and water transfer. This method is essential to achieve the long-term functionality of the sensor for on-site measurement. The proposed method does not need to introduce an expensive active pump or valve to control the water refilling. At the same time, the total volume of the water reservoir is small, which makes it convenient to operate.

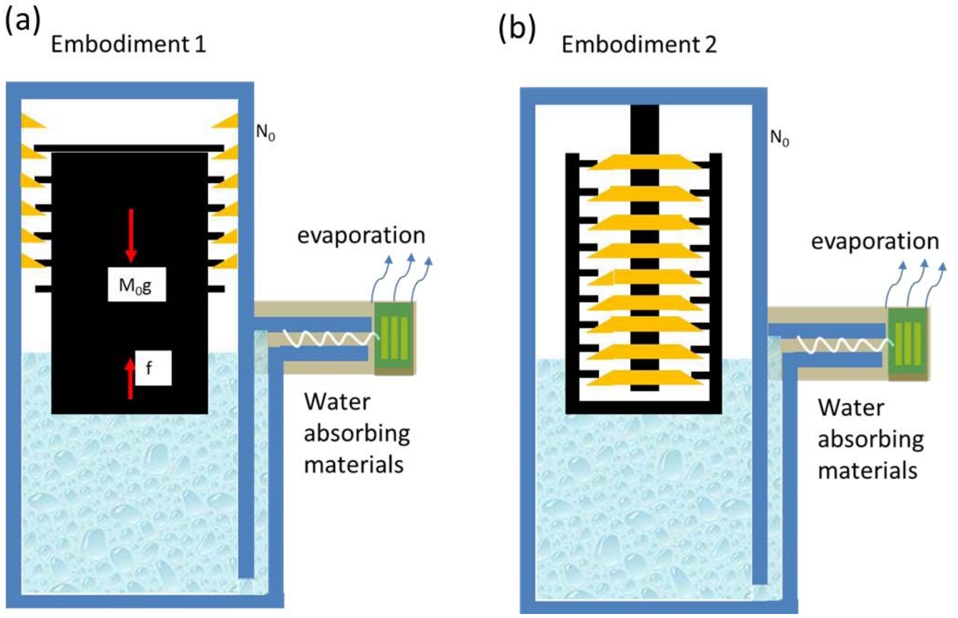

Fig. 6. Two different configurations to realize the passive water transfer/retention, where (b) can be used to miniaturized the device size.

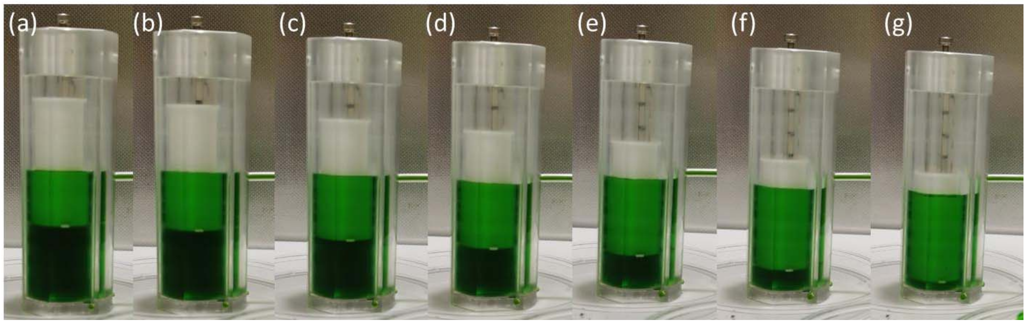

Fig. 7. A prototype to demonstrate the functionality of a passive water transfer/retention system (self-adjustable weight moves down automatically when the water is transferred out from the reservoir).

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