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Polymer/CNTs Nanocomposite for Water Level Monitoring in IoT Mobile Agriculture Application

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***Abstract*— In this paper, an IoT and mobile based smart water level controlling system has been implemented to send alert notification message to the farmers and to deliver anytime information about the water level in order to fill the tank with the necessary water. This system allows continuous pouring of the required amount of water to crops, provides continuous control from overflowing and avoids lack of water in the tank, which can cause the damaging of the pump. To this aim, WeMos D1 mini was used to determine the water level inside a container based on data received from the connected polymer/CNTs nanocomposite sensor. The use of the nanocomposite sensor and WeMos D1 mini provide us a compact, cost effective and highly precise controlling system having very low energy consumption.**

Keywords—Polymer/CNT nanocomposite pressure sensor, IoT, WeMos D1 mini, mobile agriculture application.

I. INTRODUCTION

Nowadays, Internet of Things (IoT) is desired in wide range of applications such as in agriculture and security due to the ability of the object to transfer data over the internet without requiring human to human or human to computer interaction. Therefore, IoT is evolving rapidly to meet the need of different applications. Because of the lack of water resources, the use of water needs to be controlled and managed to provide continuous pouring for the crops without risk of overflowing from tanks. Water level monitoring system using IoT is recently applied. However, wireless and low-power system is needed to work for long time without any maintenance. For that reason, the microcontroller and the sensor used in the system need to be low power. For water level monitoring, different kind of sensors are used such as capacitive, hydrostatic, ultrasonic, and pressure sensors [1-6]. The comparison between the different sensors show that the pressure sensors are the most suited especially pressure sensor based on the use of polymer/carbon nanotube due to their low cost, sensitivity and low power consumption. In fact, the working principle of this sensor is based on the change of electrical resistance due to the external load [7].

In this work, an autonomous mobile system for measuring and controlling the water level in a tank is developed to enable the user or farmer to easily operate the pump through his mobile phone and manage the task of filling up without any waste of water. The system alerts the user to turn on the motor when the level of water in the overhead tank falls below 25% and turn off the motor reach the full level.

II. MATERIAL AND METHODS

The system design consists of both hardware and software system. The hardware system comprises of nanocomposite pressure sensor, pumps, relays and microcontroller unit. The software system combines Water Container Monitoring Information System and SMTP2GO.

A. Hardware components

In this work, the proposed mobile water level control system is illustrated in Fig.1 and it consists of microcontroller, pump, and polymer carbon nanocomposite (PCN) based pressure sensor, Battery Shield for microcontroller, 2-Relay module and I2C LCD 16x2 to control the level of water in the field.

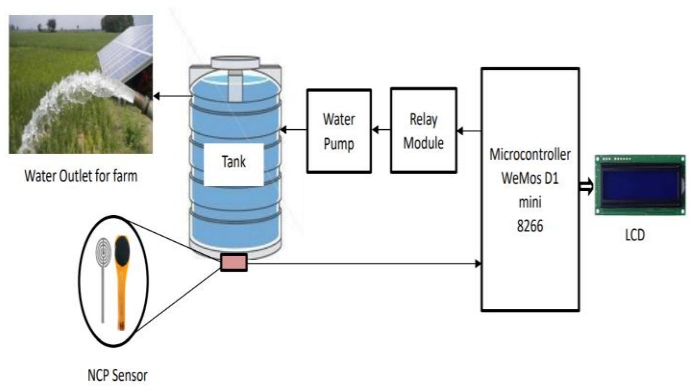


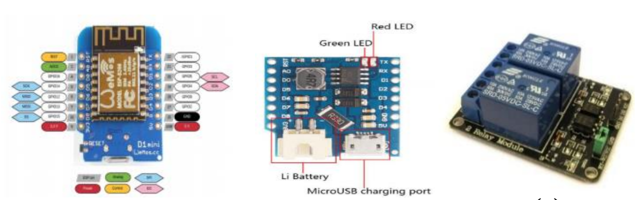
Fig. 1. Working diagram of the system

According to the Fig.1, the tank will have both; water inlet and the outlet. The tank will be filled through the water inlet and the water outlet is used for irrigation purpose in the field. Combined with compact size and low cost, makes WeMos D1 mini highly versatile and appealing to be used in this work. WeMos D1 mini is an ESP8266 based Wi-Fi development board. This microcontroller generates a trigger to make relay switch open and close.

At the bottom of the tank, a PCN pressure sensor is placed to measure the level of water as a change in resistance of the sensor. The PCN pressure sensor comprises of multiwalled carbon nanotubes (MWNT - *Sigma Aldrich*) with outer diameter 6-9 nm and length 1 µm and soft polymer polydimethylsiloxane (PDMS - *Sylgard 184*). The MWNTs are dispersed in PDMS with tetrahydrofuran (THF) solvent as the dispersion medium using a combination of ultra-sonication and magnetic stirring. 1 wt% MWNTs are dispersed in THF using ultra-sonication with *Sonoplus HD 7300* horn sonicator for 30 min at 20% amplitude. A total energy of 13.7 kJ is utilized to de-bundle the MWNTs. 5 g of PDMS is mixed to the dispersion and magnetic stirred for 60 min at 1600 rpm and 70°C. The magnetic stirring provides uniform shear to enable homogeneous distribution of the MWNTs in PDMS. Curing agent is added in the ratio 10:1 and manually stirred for 15 min ensuring homogeneous distribution into the polymer matrix. A laser cut PTFE mold with four circular slots for sensors of dimensions 20 mm in diameter and depth 500 µm is used to cast the sensors. The mold is pre-cleaned with iso-propanol and the nanocomposite material is drop casted into the slots. The mold is placed in an oven preheated to 120°C for 2 hours to cure the nanocomposite and obtain the sensor. The thickness of the fabricated sensors where measured to be between 350 µm to 400 µm. The DC electrical resistance of the sensors placed on a circular interdigital electrode are measured to be in the range of 380 kΩ ± 10 kΩ using a digital multimeter *Agilent 34401a*.

The system includes also a battery shield for WeMos D1 mini, which is a peripheral device compatible with WeMos D1 mini. It enables powering our WeMos D1 mini board using a single cell lithium battery (3.7V). It consists of a DC-DC step-up converter to increase the input voltage from 3.7 V to 5 V; all while supplying a maximum of 1 A of current. Once the battery is out of charge, the Micro USB charging port can be plugged in, which recharges the battery and simultaneously provides power to our main board. The 2 LEDs on the battery shield indicates whether the charging process is underway (Red), or the charging has completed (Green) as shown in Fig. 1b.

A voltage supply of 5V is necessary to power up the module. 2 relay module has 2 channels, this has 3 sockets each-common (COM), normally closed (NC), and normally open (NO), which is used to open or close the circuit. To pump the water, a brushless DC water pump named JT-180 is used. It is a submersible pump which can be simply dipped into a large reservoir and be controlled using the microcontroller as and when needed. It has an operating range of 4.5V - 12V DC and a power rating in the range of 0.5 - 5W. This pump has enough Q_{max} and H_{max} ratings for our usage. I2C 16x2 LCD module is also connected to the microcontroller to display messages for the user.



(a) (b) (c)

Fig. 2. Different hardware components: (a) Pin Layout of WeMos D1 mini Board, (b) Battery shield and (c) 2-Relay module

B. *Software system*

To send e-mail from the WeMos D1 mini module, we use the SMTP Protocol. This requires a third- party SMTP server and WeMos D1 mini that acts as an SMTP client. For this purpose, SMTP2GO is used.

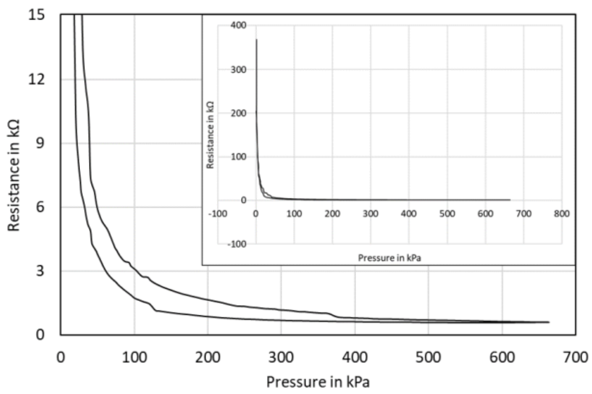
III. EXPERIMENTAL RESULTS

A. *Sensor performance analysis*

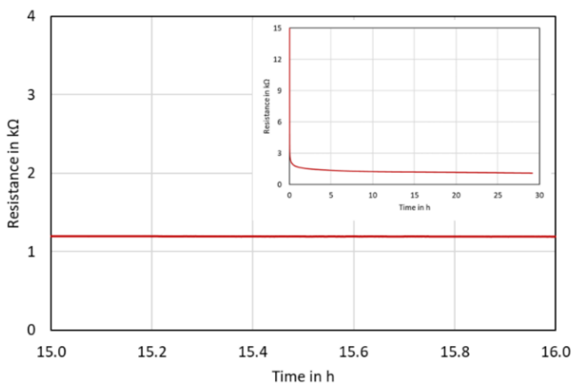
To utilize the PCN pressure sensor for monitoring the level of water, the performance of the sensor should be evaluated to ensure optimum performance and usage of the sensor. Hence, a thorough investigate on the piezo-resistive behavior of the PCN pressure sensor was performed using a custom build pressure measurement test bench equipped with a high-resolution load cell (K307M.200) allowing a maximum load of 200 N and a digital multimeter (Agilent 34401A).

The pressure sensing principle of the nanocomposite is an effect of compression and relaxation behaviour of the polymer under pressure, which results in a change of the tunnelling distance between individual MWNTs within the polymer matrix. Under pressure, the distance between the CNTs is reduced hence promoting more tunnelling with one or more adjacent CNTs. The overall resistance of the sensor decreases with increasing pressure following the piezoresistive property of the fabricated material. At no load condition, the sensor placed on top of the electrode structure exhibits a base resistance of ~380 kΩ. By the application of pressure, the resistance gradually decreases to a point of a sudden drop, at which the sensor is completely in contact with the underlying electrode overcoming the contact resistance. This is the nominal pressure (~45 kPa), at which a stable measurement of the sensor is possible, and the corresponding resistance is ~15 kΩ. Further increase in load leads to the formation of more conductive paths as the tunnelling gap between MWCNTs are greatly reduced, resulting in a further decrease of resistance. The sensor can measure up to a maximum of load of 50 N (640 kPa) with a corresponding resistance of 610 Ω as shown in Fig. 3a.

The stability of the sensor is also an important aspect to ensure stable measurement. Hence, the sensor was subjected to a constant load of 25 N (320 kPa) over a duration of 28 h. The sensor response gradually decreases at a rate of 122 Ω/h from 1.95 kΩ to 1.34 kΩ in 5 h, the decrease in resistance continues at a rate of 15.6 Ω/h from 1.35 kΩ to 1.194 kΩ in 15 h, later the change is negligible, as shown in Fig. 3b.



(a)



(b)

Fig. 3. (a) Piezoresistive performance of the PCN sensor and (b) Stability analysis on the PCN sensor

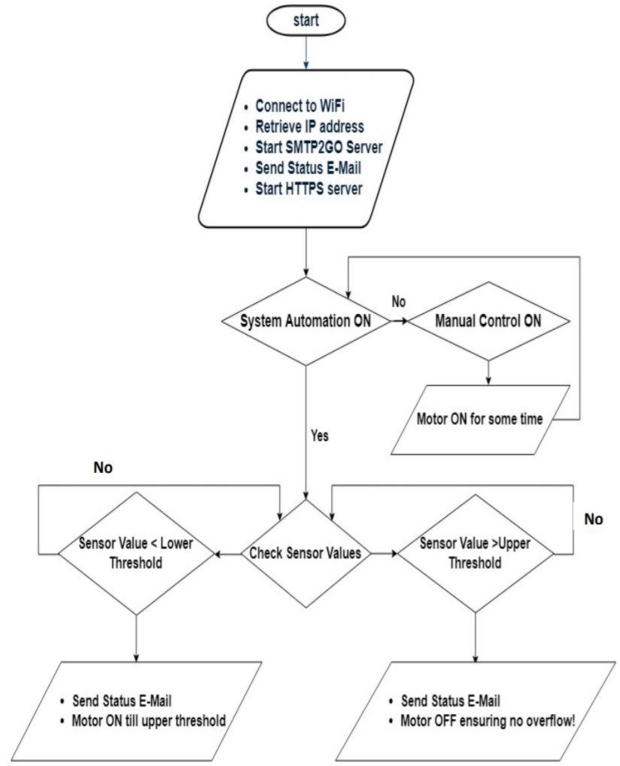
B. Water level control system

The water level control system is presented in Fig. 4 with the flowchart of the software program that will be executed with WeMos D1 mini. The system is started and connected to Wi-Fi. The connection to wi-Fi and IP address are displayed on the LCD using a remote device whenever required. "Https" and "SMTP2GO" servers are initiated. E-Mail notification saying "YOUR SYSTEM IS ON" is sent to the user through SMTP2GO server and the connection to the user remote device is established through https server.

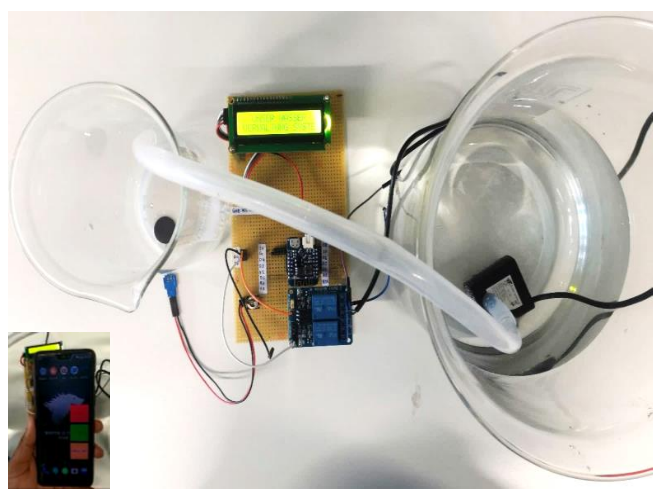
Using a voltage divider circuit, the value of resistance change of the NCP sensor is calculated to estimate the water level. The sensor output values are measured and compared to the value of sensor resistance at the predefined thresholds.

If the water reaches the critical level, E-mail notification saying "Water Level is Critical" is sent. Simultaneously, motor is turned on by the microcontroller. Motor is enabled for 2 seconds and then turned off and corresponding sensor values are read again. This process is repeated till the water level in the tank reaches upper threshold. Then, the pump is turned off.

In case that the water level is above the upper threshold, E-mail notification saying "Tank is full" is sent as shown in Fig. 5c. Moreover, if the motor is on, it is automatically turned off.



(a)



(b)

Fig.4. (a) A flowchart of the software program executed by WeMos D1 mini and (b) Water level control system using smartphone control

IV. CONCLUSION

Because of the water scarcity, monitoring water level, especially in agriculture application is becoming a necessity to avoid waste of water and to enhance the quality of agricultural crops by controlling plants need.

In this work, the proposed water level monitoring system was successfully implemented and provides the farmer a compact, cost effective and precise solution to be able to fill the water tank from anywhere as the system is connected to the internet using a mobile phone. In addition, the proposed system is user–friendly, which makes their use easy and simple for people of any age. This system has also low energy consumption as it uses nanocomposite pressure sensor, which has high ohmic resistance.

Moreover, there is no possibility using the developed system of water overflow since the motor will be turned off automatically once there is enough water in the tank. Thus, water level is monitored autonomously.

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