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Design and Construction of a Prototype Cost-Effective Water Table Level Detector for Irrigated Fields

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Abstract
It is evident that water table depth is one of the most important physical features of a cropped field, and that its measurement is vital for optimum management. The scarcity of such data in developing countries could be attributed to high cost of commercially available sophisticated devices and their limitations due to their deployment for non-agricultural purposes. In this research, a resistive ground surface to water level depth measurement device was conceptualized, designed and constructed using readily available cost-effective materials for use on irrigated fields in Kadawa area of Kano River Irrigation Project (KRIP). The device concept was simulated with LabCenter Proteus 8.8 proprietary software and then constructed. The operational concept of the device is that when powered on, submerged resistors along the detector resistive chain shuts with the depression of a push button and corresponding unsubmerged depth acquired as voltage drop across a meter and a translating Arduino microcontroller. The device was successfully constructed with some limitations in the availability of required resistors' design specification and modern assembly technology and equipment. The detector would further be calibrated and validated based on laboratory and field experiment to ascertain it applicability in irrigated fields.
Keywords: Cost-effective; Digitized water level detector; Irrigated fields; Resistive transducer; Voltage drop; Water table.

Introduction

Measurement of water level is usually conducted manually with associated human error. In water-related fields such as pre-flood warning system, irrigation system, hydroelectric power plant and research, water level data is important (Saraswati *et al*., 2012). Amongst a variety of parameters such as level (or depth), temperature, conductivity, turbidity, and pH, the water level is the most fundamental one that needs to be monitored on a real-time basis for securing water management system (Lee *et al*., 2020).

Enormous research spanning decades to present were conducted on the relationship between crop-yield and water-table depth, and the causal mechanisms involved in the relationship (Baird and Low, 2022). Thus, arriving at the conclusion that, monitoring groundwater fluctuations is mandatory to envisage the composition of terrestrial water storage (Masood *et al*., 2022). Despite the obvious need to monitor groundwater, seasonal variation and fluctuation, climate change and impact of human activity on groundwater resources are sparsely documented (Harun and Che Kamaruddin, 2016); consequently, data for water table measurements are being scarce for certain areas (Zhang *et al*., 2020). This could be attributed to commercial water level sensors and monitoring equipment being expensive and as well imported into developing countries (Loizou *et al*., 2016; Anyanwu *et al*., 2012). Furthermore, the existing techniques for liquid level sensing have either been applied over a small measurement range, or they are not convenient for transportation, installation, and long-term maintenance (Loizou *et al*., 2016). Also, most of commercially available options are not developed for agricultural deployment. Therefore, limitations are encountered on deploying the commercial equipment on agricultural fields. The specificity of design to usage purpose is paramount as each water level measurement system and principle has its peculiar limitation as reported in Asyiddin (2007). The steel tape, dipstick, corn stalk and chalked tape deployed in Kadawa fields are not suitable. On the other hand, automatic devices that accurately log the behavior of water levels at relatively short time intervals are preferred for research purposes because they better capture the dynamics of the water level with time. Consequently, this study developed a prototype resistive water table level detector as an alternative to conventional dipstick, steel tape, float and corn stalk used for instrumentation and data collection for water table studies at Kano River Irrigation Project, Kadawa.

The developed resistive water level detector bridges the gap between expensive commercial geophysical equipment and local/conventional method of water level determination. Furthermore, it introduces an automation of the conventional physical methods used for studies on the field and offer the advantage of a digitized and non-intrusive in-situ depth to water table data collection as voltage drops with level fluctuation. The major advantage of which include being safe for operation and ease of output conversion to another measure for electrical determination using resistive transducer (Singh *et al*., 2018). It also simplifies usage at multiple points with no technical difficulty by its uncoupling point unlike commercially available sensors that are primarily fixed at permanent monitoring wells. Therefore, this development will assist with easy in continuous monitoring water table at the Kadawa.

2.0 Materials and Methods

2.1 Materials

In this study, various category of materials and tools were used which include but not limited to piping and plumbing tools and materials, electronic tools and materials and instrumentation tools. These materials were employed in the development of the level detector circuit, sensing element and design simulation. Tables 1 and 2 present the electronic components and research instrumentation tools respectively with specifications and functions.

Table 1: Electronic Components, Specifications and Functions in the Circuit

S/N	Component	Specification	Function
1	Arduino Uno R3	Outstanding revision with an ATMEGA328P-PU micro controller, high performance, low voltage requirement of 1.8-5.5 V with operating voltage of 7–12 V from external supply and operational temperature support in the range of 40 ^{0}C to 85 ^{0}C	Programmable development board that processes input signal and delivers output to display of indicated depth measurement
2	Vero Board	Reusable solder less board, 6.5×4.4×0.3 inch with two distribution strips	Tests all circuit connections
3	Display Module	16 by 2 liquid crystal display (LCD), 4.7 V-5.3 V, Alpha numeric, 8- and 4-bit mode enabled	Shows microcontroller output
4	Jumper	Male to male	Transmission lines connecting assembled components on the board
5	Battery	Rechargeable 3.7 V lithium-ion battery	Powers the entire circuit and the sensing element
6	Resistors pack	1 kΩ fixed value, metal film type	sensing element
7	Switches, keys, and push button	SPST rocker switch, –10 °C to +55 °C, average 10,000 operating cycle	initiate command by completing the circuit/ execute an action

Table 2: Instrumentation Tools

S/N	Equipment	Model	Specification
1	Digital Multimeter	DT830LModel	Voltage resolution of 10 mV and accuracy of ± 0.8 % of reading +5D
2	Digital Multimeter	MAS838L	Resistance resolution of 100 Ohm and accuracy of ± 1.0% of reading+4D
3	Soldering Iron		220V, 250 – 400 ^{o}C

4	Proteus Software	LabCentre 8.8	Circuit conceptualization and simulation

All circuit elements were bought at Gwandu Road off Katsina Road, Kaduna. The device construction was carried out at the Departments of Electrical Engineering of Kaduna Polytechnic and Ahmadu Bello University (ABU), Zaria.

2.2 Operation of the Water Level Detector

The operation concept of the level detector was designed such a way that on switching on the device, the micro controller, the LCD, and the sensing element receive power and initiate. The LCD screen display startups instructions coded to the micro controller for a minute. On depressing the push button, the sensor receives input voltage from the batteries and reads voltage drop from the resistors after division at the point of the voltage divider to the last submerged resistor as schematically presented in Figure 1.

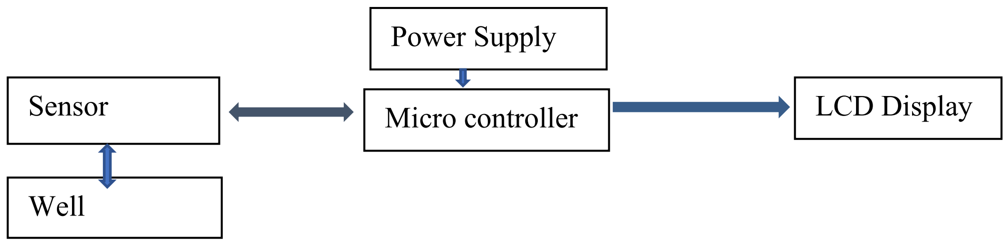

Figure 1: Block Diagram of Water Level Detector Circuit

The voltage across the free unsubmerged resistors is transferred to the micro controller as the level. The microcontroller then makes comparison based on the loaded coding and the output is displayed. The process as described above is repeated as a loop with the push button press contrasting Popa *et al*., (2008) who reported resistive transducer design dependability on dryness to operate. The detector step by step operational flow chart process is mapped as in Figure 2.

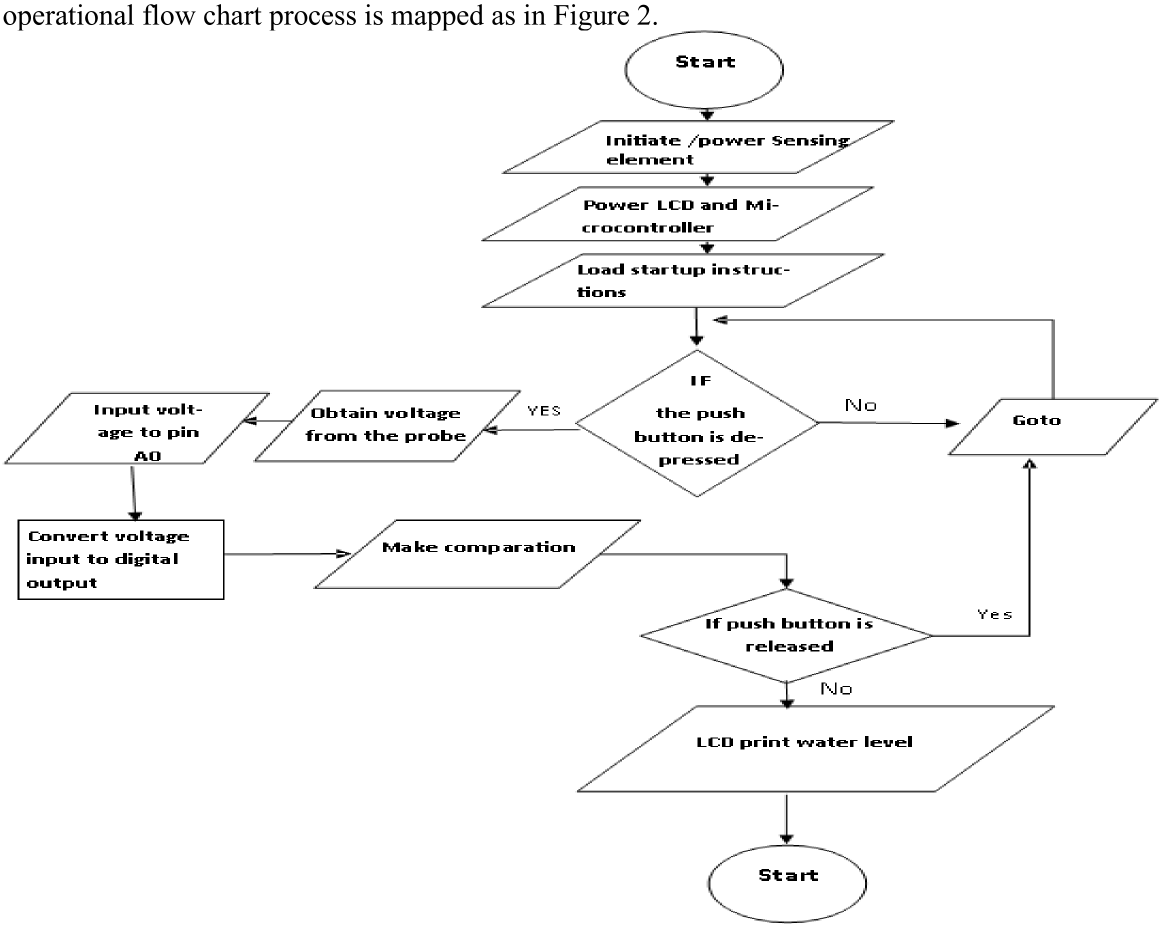

Figure 2: Circuit Operational Flow Chart Diagram

2.3 Circuit Design Procedure

The circuit design was carried out using Proteus Design Suite 8.8; a proprietary software tool suite by LabCenter Electronics Limited. The design was achieved through the following steps (Steps 1 to 11).

Step 1: The installed Proteus Design Suite 8.8 windows software application was launched.

Step 2: A complete list of components was created according to the conceived water level detection circuit that is 100 Nos. 1 kΩ fixed resistors, a 10 kΩ variable resistor, 4 Nos. 3.7 V battery, single switch, push button, Arduino Uno board, LCD screen and Voltage regulator etc. as shown in label B of Figure 3.

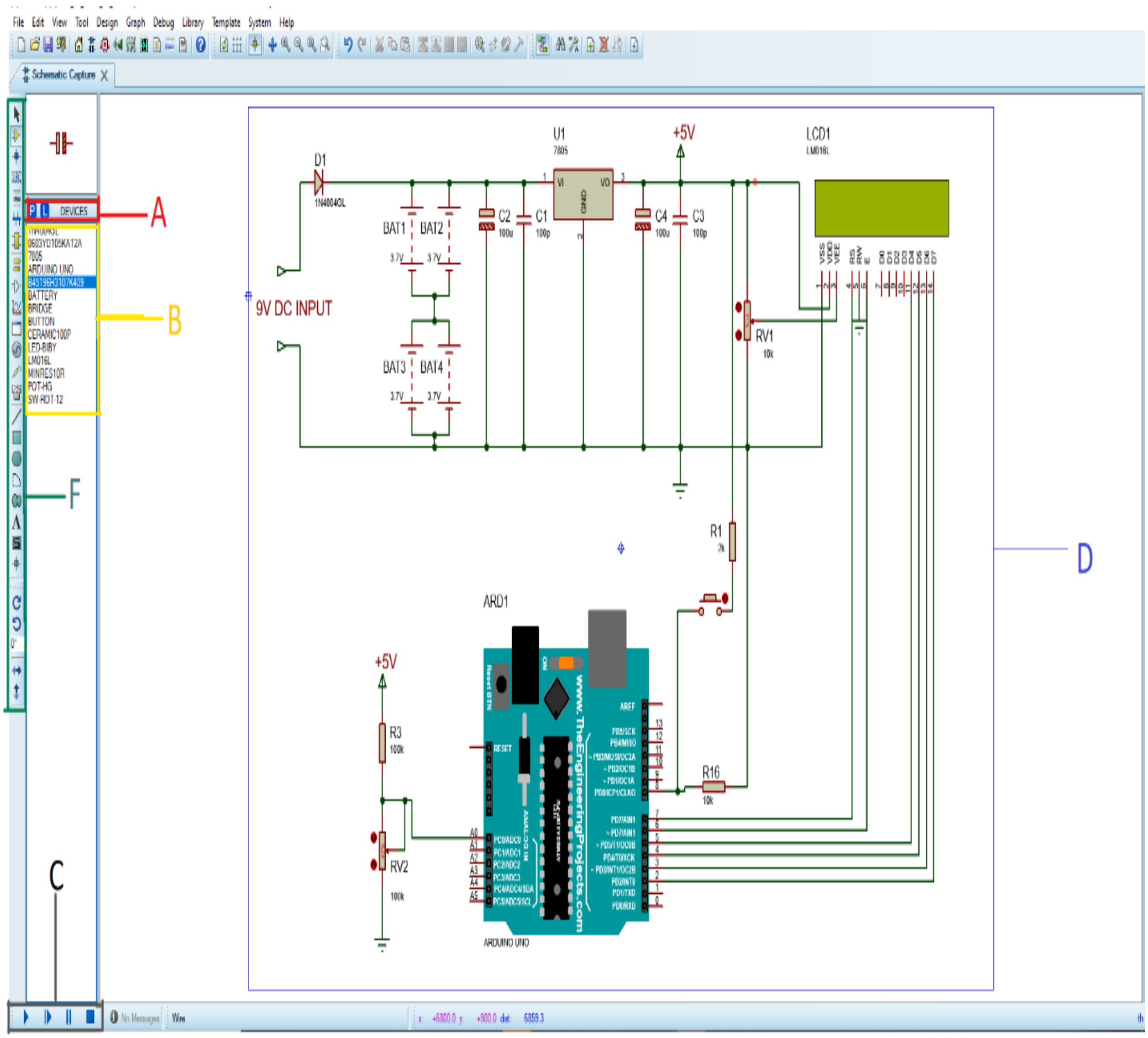

Figure 3: Labelled Water Level Detector Design Environment on Proteus Software

Step 3: button on the left side vertical bar (labelled F) was clicked for package mode enabling.

Step 4: Package mode displayed “P” and “L” (labelled A).

Step 5: Clicking “P” launched new window containing all the components parts in Step 2.

Step 6: Listed part were double clicked for category make and type selection as shown in Figure 4.

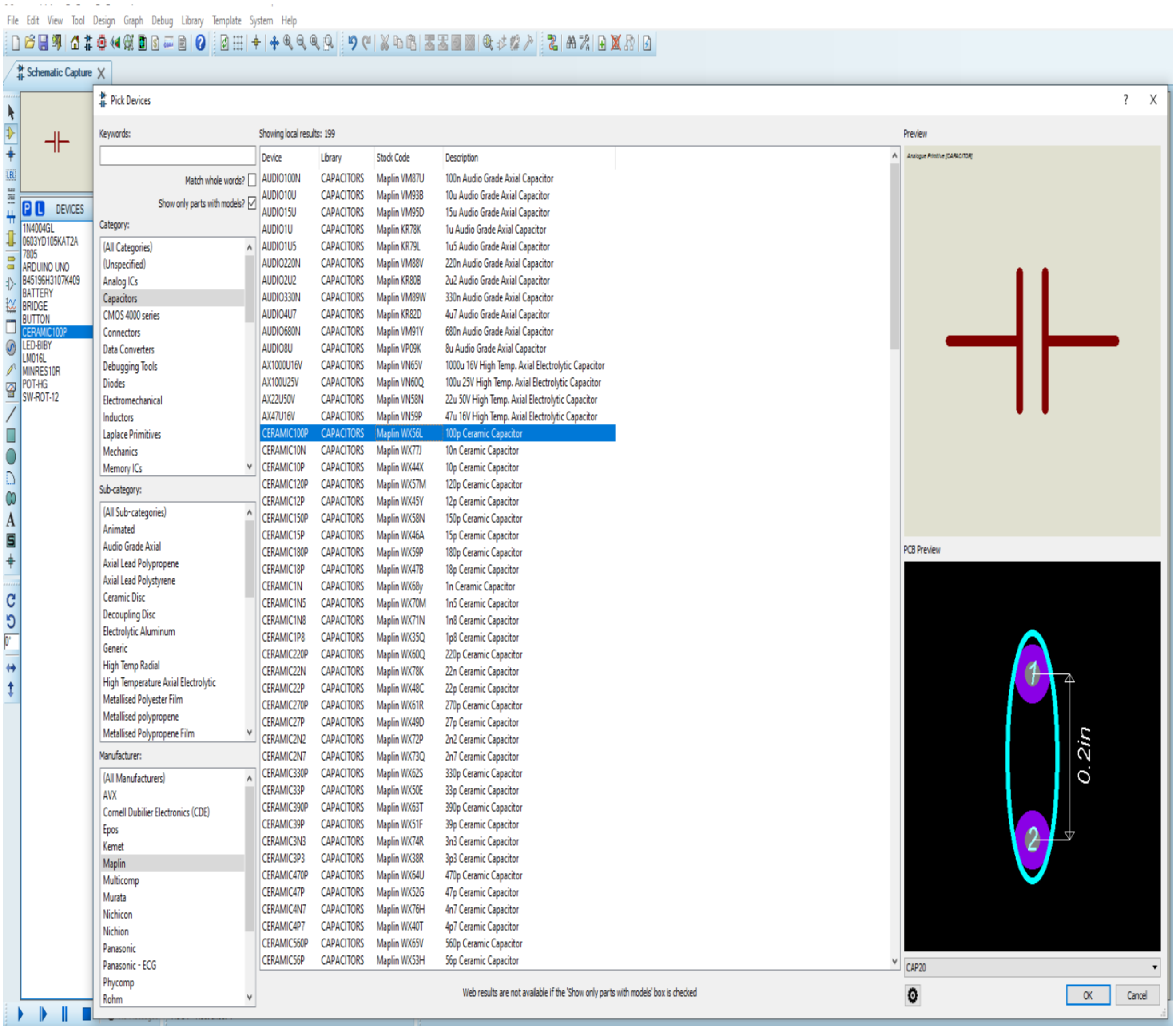

Figure 4: Circuit Component Category, Make and Type Selection Using Proteus Software

Step 7: The procedures from Step 2 to Step 6 were repeated for each component design in the entire circuit for the water level detector.

Step 8: Circuit routing was conducted on the software to connect the designed circuit components.

Step 9: Simulation was activated using run button/play icon on the bar labelled C in Figure 3 after closing the circuit switch.

Step 10: Variable resistance of the designed sensing element (RV2) was varied continuously after obtaining a depth of 0.000 m display at RV2 full-scale 100 kΩ on simulation.

Step 11: The program was saved and closed.

2.4 Construction of the Water Level Detector Circuit (Assembly and Routing)

The computer designed and simulated circuit was implemented and the circuit connections were made to actualize the conceptualized water level detector.

2.5 Programming of the Water Level Detector

The Arduino platform was programmed with code to interpret the digital signal received from the output of the ADC circuit using Arduino IDE. The programming was done after establishing the maximum voltage value (when dry) and minimum value (when fully submerged) given from the resistors of the sensing element. The level detector resolution was established from its range, hence a calibration equation obtained from experimentation was deduced in coding to give level value.

4.0 Results and Discussion

4.1 Probe Length Calibration

Resistors placed at 0.015 m interval were counted and results were tabulated (Table 3). A curve of actual fabrication length versus design length was carried out to check fabrication misalignment, shown in Figure 5. The curve indicates a good fit of design translation to fabrication of the sensing element (probe).

Table 3: Sensor Length Calibration Data

S/N	Resistor position	Multiplier	Length (cm)	Actual length (cm)	Depth (cm)
1	6.5th	1.50	6.50	9.75	10
2	13.5th	1.50	13.50	20.25	20
3	20th	1.50	20.00	30.00	30
4	26.5th	1.50	26.50	39.75	40
5	33.5th	1.50	33.50	50.25	50
6	40th	1.50	40.00	60.00	60
7	47th	1.50	47.00	70.50	70
8	53.5th	1.50	53.50	80.25	80
9	60th	1.50	60.00	90.00	90
10	67th	1.50	67.00	100.50	100
11	73.5th	1.50	73.50	110.25	110
12	80th	1.50	80.00	120.00	120
13	87th	1.50	87.00	130.50	130
14	94th	1.50	94.00	141.00	140
15	98th	1.50	98.00	147.00	150

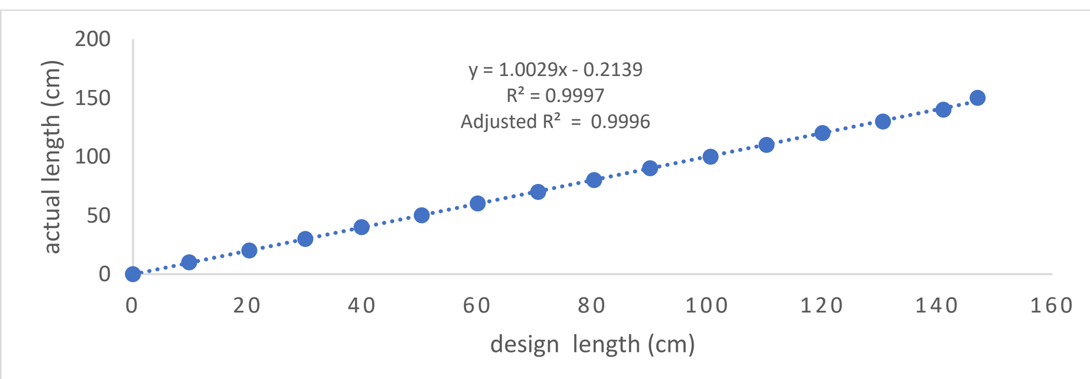

Figure 5: Sensor Length Calibration

4.2 Constructed Water Level Detector Board and Simulation Output

Applying procedures as outlined in sections 2.3 and 2.5 yielded simulation results with Proteus 8.8 software as depth displayed in meters on the water level detector LCD. The display indicated 0.0000 m depth with a completely dry probe; that is at full scale resistance of 100 kΩ with RV2 in simulation. Conversely, with decreasing resistance, an increase in depth was observed to 1.5 m depth recorded at 0 kΩ of RV2. The fabricated circuit board outcome is presented in Figure 6. Outcome obtained herein are consistent with Yao *et al*. (2009) that demonstrated matching of circuit simulation and fabrication results. However, Mahmudul-Hassan (2020) reported that planning, software simulation and hardware implementation as not easy and freely matching.

Figure 6: Fabricated Detector Circuit Board

The application of water management schemes requires the installation of water level data-acquisition systems in multiple, geographically isolated large-scale distribution networks (Loizou *et al*., 2016). Hence, the detector was designed portable for point-to-point data collection and proved effective for deployment at Kadawa using hand augered wells as no observation well was found within the study area. More so, its sensing element span was site specific considering the maximum and minimum depth to water table (0.2 – 1.5 m) , seasonality and irrigation as reported in Sobowale *et al.* (2014). The developed prototype cost is significantly less at 72,400 Naira (about 100 USD depending on FOREX) compared to options such as WL400 and WL16 series with prices in the range of 685.90 USD – 1,198.99 USD.

Conclusion

This study was carried out with the aim to design and construct a prototype cost effective ground surface (GS) to water level (WL) detector for irrigated fields. The study set out to address the scarcely documented GS-WL depth fluctuations, use of traditional measurement method such as corn stalk at Kadawa and the cost of geophysical devices for agricultural studies. The device concept was simulated with LabCenter Proteus 8.8 proprietary software and then constructed. The operational concept of the device is that when powered on, submerged resistors along the detector resistive chain shuts with the depression of a push button and corresponding unsubmerged depth is acquired as voltage drop across a meter and a translating Arduino microcontroller. The designed and fabricated water level detector is effective in determining water depths within the range of 0.2–1.5 m. Sensing element materials (resistors) selection was limited to the choice of buying from what is available in the market. Therefore, the readily available resistors in the market that gave best result were resorted to in place of the required specification for the designed detector circuit. Non availability of modern assembly technology and equipment such as solder paste printing machine and automated optical inspection machine denied the highest level of precision attainable for the assembled circuit. Consequently, available tool within the study laboratories were used for soldering, testing and other assembly operations. Non rechargeable lithium-ion batteries drained fast on continuous data collection as such, the circuit was modified to use rechargeable cells to save cost and to limit the need of often casing removal for battery replacement. The device is recommended for use in similar irrigated fields with water table within the detector span. It could also be used in monitoring water level in storage reservoirs when continuous water depletion and refill data is of interest.

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