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DEVELOPMENT OF AN ARDUINO TEMPERATURE DATA LOGGER - A FRAMEWORK

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Abstract

Temperature monitoring is an integral part of human daily living. Generally, the design process involved in logging temperatures has witnessed significant growth with the use of different platforms. The procedure of data logging became inherent especially on farm products and food security. Due to high temperature and moistures, most farm produce waste before getting to the market and a larger percentage of which high temperature is culpable. Sophisticated, durable and efficient storage facilities are very expensive for farmers to afford, this contributes to loss in farm produce. It is not certain that the farm produce would reach markets the day of harvest hence, this work carried out a survey and developed a five-channel Arduino Temperature Data Logger (ATDL) framework suitable for vehicle compartments to monitor the temperature while conveying farm produce from the farms to local markets. The developed framework is microcontroller-based data logger as an improvement on previous attempts to allow low-income communities, homes and small-scale industries across different fields to monitor, measure and store variation of temperature values. The novelty of this framework is the merging of hardware and software components to provide better user experience and interaction.

Keywords: Food security, Temperature, Microcontroller, Agriculture

Introduction

A Data Logger (DL) is a programmed electronic device that gives room for measurement, documentation, analysis and authentication of various parameters like (voltage, current, humidity, temperature and pH) over a period with desirable time intervals. The basic requirement for a data logging system is acquisition, online analysis, logging, offline analysis, display and data sharing (YIK, 2012). Research carried out by Food and Agriculture Organization (FAO) found that approximately 14% of food produced is lost between harvest and retail, while an estimate of 17% of the total global food production is wasted, 11% in households, 5% in food service and 2% in retail (Canton, 2021). It was established by the United Nations Environment Programme (UNEP) index report; that food waste annually in regions of higher temperature is recorded at 37,941,470 million tons. (Canton, 2021; Emadi & Rahmanian, 2020; Pernet & Ribi Forclaz, 2019; UNEP, 2021). In line with this background, this project is aimed at designing and developing a multichannel temperature DL capable of automatically capturing temperature data at 30 seconds interval for a day and saving it for later use or analysis towards reducing food wastage and enhance food security especially during transportation. When temperature is monitored, it provides indication for food wastage mitigation measures to be in place and avoid food wastage accordingly. The multi-channel ATDL framework proposed in this work can be applied for temperature measuring, monitoring and recording in various industries such as in food processing, pharmaceutical manufacturing, farm storage units and stages of component assembly and semiconductor fabrication. The quality temperature data to be analysed with this framework will make it a better choice for research and analysis when implemented. The output can continuously monitor experimental process, temperature of physical phenomena in automotive process and test chambers.

A DL accepts data inputs from sensors implemented in the circuit depending on the target purpose and the parameter being measured. Common examples of such input sensors are temperature sensors, sound sensors, pressure sensors, flame sensors, light sensors, electrical sensors, contact sensors, water sensors and flames sensors. The main components of DL are microcontroller (μC) (which could be an Arduino, Universal Synchronous/Asynchronous Receiver/Transmitter (USART), Peripheral Interface Controller (PIC), Integrated Electronics (INTEL) 8051, 8052, AT89s52), a sensor to capture values, a Serial Data (SD) (which serves as an internal memory for storing data) and a power supply mechanism (i.e., battery powered, Universal Serial Bus (USB) and Alternate current supply). Temperature is one of the top five parameters measured in the world annually (Kuchta *et al.*, 2005), which contributes to the advancement of its measuring devices yearly for minute purposes to large scaled purposes. The major consequence of DLs over some measurement device is its ability to capture data automatically within a specified period depending on its source of power. This feature minimizes human efforts in monitoring and errors in recording and documentation of values. The five channel ATDL framework developed focuses uses a miniaturized electrical components and devices aided by an Electronic Design Automation (Proteus 8 Professional) and Computer Aided Design (Fritzing) software for design and stimulation, Arduino Integrated Development Environment for software program integration with all components used and skillful use of Arduino Programming intertwined with C++ programming.

Data logging system and processes involved has proved its significance for the past two decades, in its involvement in various areas: power systems, solar systems, agriculture, food processing plants, hydrographic recording, road traffic counting, deformation monitoring, components assemblage, semiconductor fabrication, environmental research, building monitoring, automotive, civil engineering and manufacturing. The advent and re-modification of this technology has proved its usefulness in various areas of scientific and engineering research in order to solve rising problems. This work is tailored to use this concept in enhancing the agriculture sector and improve food security by reducing damage emanating from heat.

Data Loggers (DLs)

As introduced earlier, logging is a process of recording events (Adebisi et al., 2022). When involved in fieldwork, laboratory testing, system testing, product testing and other activities it can then be regarded as one of the instruments or research methods that is used to acquire more data or information as an integral part of the iterative design in scientific/engineering cycle. Data logging is commonly used in scientific experiments and in monitoring systems where there is the need to collect information faster than a human can possibly collect the information and in cases where accuracy is essential (Kale *et al.*, 2007). The DL is an invaluable tool to collect and analyze experimental data, having the ability to clearly present real time analysis with sensors and probes. It is also able to respond to parameters that are beyond the normal range available from the most traditional equipment (Waghmare & Chatur, 2012)

Adebisi and Babatunde (2022), before the practice of data logging, different instruments were designed, built and proposed to perform the function a DL such as strip chart recorders and circular chart recorders, magnetic tape, punched paper tape and roll chart recorders. Over the years, DLs has reduced drastically in size due to the use of simple electrical components that possesses more features that are incredible with evolving designs. The reduction of DLs size and choice of components has contributed immensely to its portability, reliability, performance and lesser power consumption. This improvement in technology has helped in the advancement of the DLs versatility in different sectors or field (i.e., manufacturing industry, energy, food processing, research and engineering) and having it as a stand-alone device, assisted in providing for the need of data analysis and data collected.

There exist different types of DLs, which include Wi-Fi DL, universal input DL, Bluetooth DL, remote DL, Radio Frequency Identification DL, Modbus DL, High speed DL, multi-channel DL, paperless DL, mechanical DL, and electrical DL (Photopoulou *et al.*, 2015). A wide range of factors could affect the choice of a DL ranging from reliability, cost, usability, timeliness and high data accuracy, efficiency, alarm indication of preferred value limit, ability to withstand high temperature if used in hot regions among others. DLs has a wide range of application in different fields globally in storing data values regardless of the parameter being measured. The Arduino Temperature Data Logger (ATDL) considered in this research is a µC-based data logger specifically designed, implemented and programmed to capture record and store temperature data at different time interval for use and analysis. Most TDLs uses Resistant Temperature Detector sensors, thermocouple and thermistors in its circuit implementation. TDLs are easy to deploy as versatile stand-alone devices (Medojević *et al.*, 2018).

Review of Literature

A survey of previous research and approaches is carried out. The synthesis and implementation across different literature which has contributed to the use of data logging system and its enhancement is explored and considered for the development of the proposed framework. In Gandra *et al*., (2015), an Arduino Nano was used as a µC in its experimental setup alongside a micro SD card and Real Time Clock to create light weight, small and modular DL used to record environmental and physiological parameters such as frequency, light intensity and temperature. The authors connected three sensors to the Nano logger on a breakout board alternatively; MMA7341L triple- axis accelerator sensor was used to measure both static (gravitational) and dynamic (inertia) acceleration of a sea plant (Fucus spiralis frond). MAX31855 with a k-* type thermocouple coupled with an intertidal limpet was used to measure temperature. A CNY-70 infrared sensor together with an AMP-3 amplifier was applied to amplify the signal from the sensor for heartbeat muscle measurement. The Nano logger has proven that it can be used with a vast array of inexpensive analog and digital sensors (Gandra *et al*., 2015).

Osinowo *et al.*, (2021), conducted a research based on monitoring the meteorological situation using Arduino Mega µC-based data acquisition system to measure, record and display atmospheric parameter values (i.e., temperature, relative humidity and wind speed) from analog sensors interfaced with the Arduino Mega µC through an Analog – Digital Converter and data logging process. The Liquid Crystal Display module is interfaced with the µC to display parameter values from the sensors. Data acquired are stored in a .csv file on a micro-SD card In addition to this, various studies that focused on multi-channel ATDL design and implementation using different types of Arduinos µCs and temperature sensors were presented in their literature. Their work is similar to that of Nhivekar & Mudholker, (2011) who presented a research paper based on the development of an AVR ATMEGA 32µC DL that measures environmental parameters (i.e. temperature and relative humidity). The data is transferred to a PC for analysis and printing. The monitoring of the parameters is done via SMS. (Simões & de Souza, 2016), created an automated Data Acquisition System using big data and IoT concept to obtain local scaled temperature and relative humidity data. The DAS is a constructed circuit made up of DS3231, RTC module, Arduino Nano, DHT11, Ethernet module and OGC SWE software to enable the inclusion of sensors and sensed data on the internet. (Álvarez et al., 2016; Ojike *et al.*, 2016) explained previous research and experimental work done to compare measurement of technical features between DS18B20 sensor and TMP275, with the aid of Arduino Nano to provide a data logging platform. The results proved DS18B20 provided a desired ratio of accuracy in price and performance, on the later, they further developed a single point low temperature ATDL, using a LM35 temperature sensor, spark fun micro-SD shield, Arduino Uno, SD Card, LCD 16 x 2 module for automatic data capture of temperature values. This design carried out evaluation on its circuit performance and compared its results of accuracy with different thermometer.

Similarly, an Arduino µC based DL that monitors and measures humidity, temperature, and pressure in real time process dynamics was proposed by (Sawarkar & Bramhe,

2019) . The system enables monitoring of the system energy consumption through a webpage with the aid of an ESP 8266 Wi-Fi module to send archived sensors data to the web page, if implemented, the result can be accessed through IP address, and however no record of design was found. Ogundimu et al., (2021), constructed a low cost logging meter to measure temperature, humidity and solar irradiance, using ATMEGA 328p, Arduino Nano, PT202C, DHT11,RTC Module, Micro SD, 20x4LCD module as a follow-up on (Méndez-Barroso et al., 2020) where authors discussed the development of a low –cost multi parameter probe (LCMP) to detect and measure water, temperature and oxygen. Their discussion covered Lifecycle Management Process Integrated Data integration with Arduino Nano connected to different sensors coupled with real time clock module and SD Card for data storage.

Roihan & Koestoer, (2020) evaluated the performance of a multi-channel Arduino Uno based solar measuring layer. This systematic approach builds a group DL of three units of sensor (DS18B20 waterproof, DHT22 and k-type thermocouple with MAX6675 modules with each having corresponding Arduino Uno and data logging shield to store data independently. The Arduino Uno reads and write to the SD- card in real time; the SD- card acts as a storage unit for each data logging system for 24- hours concurrently with a limitation to solar layers and not in any way related to agriculture.

Microcontroller(s)
A µC comprises of micro sized transistors embedded on a circuit (Spasov, 1993). They are small, low cost and are a self-contained computer on a chip that can be used as an embedded system (Davies, 2008). µC is a computer on a single integrated circuit that includes a RAM, I/O ports, CPU and some form of ROM. The basic part of the data logging system is made up of a compressed µC and its functionalities which is critical to the overall operation and system performance. Its composition includes processors, memory I/O ports, RAM, serial bus interface, ADC, timers, flash memory, discrete electrical components and most µCs have EEPROM, with all components having its corresponding analog and digital pins which aid interfacing a connection with other modules, sensors, logging shields and electronic components, depending on the circuit design. µCs functions as an embedded device allows it to automatically manage devices and inventions due to its inexpensive nature. Before the creation of Arduino in 2005, circuit designers in their designs used the likes of Peripheral Interface Controller, 8051 and Low Pin Count. Major types of Arduinos that has been used in designing ATDLs are: Arduino Uno, Arduino Mega and in recent cases Arduino Nano is being used in this new work. Table 2.1 summarizes a list of references and the various µC used in their various locations and period.

Table 2.1 Summary of micro controller used in TDLs implementation.

S/N	Reference	Location	Year	Microcontroller
1	(Perez et al., 1997).	Mexico	1997	DS5000T
2	(Okwudibe & Akinloye, 2017b).	Nigeria	2017	PIC18F452
3	(Oladimeji et al., 2020).	Nigeria	2020	Arduino Uno
4	(Bongulto et al., 2016).	Philippines	2016	Arduino Mega
5	(Nhivekar & Mudholker, 2011).	India	2011	AVR AT mega 32
6	(Dedrick et al., 2000).	N.Y, USA	1999	PIC16C73A
7	(Divakar, 2013).	U.K	2013	LPC21428
8	(Lockridge et al., 2016).	USA	2016	Arduino Uno & Mega
9	(Fuentes et al., 2014).	Spain, China	2014	Arduino Uno
10	(Roihan & Koestoer, 2020).	Indonesia	2019	Arduino Uno
11	(Osinowo et al., 2021).	Nigeria	2021	Arduino Mega

Temperature Measurement
Temperature is the degree of hotness or coldness expressed in terms of several measurements' units such as Fahrenheit, Kelvin, and Celsius. The earliest temperature-measuring device is the thermoscope, invented in 1593 by Galilei Galileo (Machado & Tao, 2007). This device could illustrate the changes in temperature values but for sometimes might provide varied results. It has since then witnessed series of improvements and several phases until different temperature measuring devices were invented. Temperature devices has gotten from large to portable devices such as sensors, modules, probes, Resistant Temperature Detector and TDLs. Table 2.2 is a summary of temperature sensors, location and year of usage.

Table 2.2 Summary of different temperature sensors, location and year of usage.

S/N	Reference	Location	Year	Temperature Sensor
1	(Gandra et al., 2015).	Portugal	2014	K-type thermocouple
2	(Bongulto et al., 2016).	Philippines	2016	DHT11
3	(Perez et al., 1997)	Mexico	1997	LM324
4	(Dedrick et al., 2000)	N. Y. USA	2000	Thermistor
5	(Okwudibe & Akinloye, 2017a).	Nigeria	2017	LM358
6	(Divakar, 2013)	U. K	2000	LM325
7	(Roihan & Koestoer, 2020).	Indonesia	2020	DS18B20& MAX6675
8	(Nalavade et al., 2019).	India	2019	K-type thermocouple
9	Alvin Kuzi Quan	Malaysia	2021	LM35DZ & K-type thermocouple
10	(Osinowo et al., 2021).	Nigeria	2021	DS18B20
11	(Susilo et al., 2021).	Indonesia	2020	DHT22

Methodology

Several methods have been used as indicated in the review, however this work proposes a hybrid approach that enable the use of a 5 channels Arduino Temperature Data Logger (ATDL). The five channel ATDL framework developed uses a miniaturized electrical components and devices aided by an Electronic Design Automation (Proteus 8 Professional) and Computer Aided Design (Fritzing) software for design and stimulation, Arduino Integrated Development Environment for software program integration with all components used and skilful use of Arduino Programming intertwined with C++ programming.

This is illustrated in the block diagram shown in Figure 1. It shows the diagrammatic representation of the ATDL. The Arduino Nano is the heart of the system because it gives commands and instructions to the different modules connected to it. Results are meant to be displayed on the 16 × 2 LCD module screen. The method supports operations of each component and their inter-dependency on each other to operate as a complete ATDL system. The major sub sections of this methods are; Power supply (9 volts) or a Mini-B USB cable connection to a PC. Timing Control, a DS3231 real time clock module fit to control the time and date sequence. 12C communication technique using SCL (Serial Clock) and SDA (Serial Data) pins to enable the Arduino Nano to read data from the RTC module, when the date and time is set on it. In addition is the Data Transfer subsection, of the Arduino Nano which takes multiple analog temperature readings from DS18B20 sensor and then converts' data using its in-built Analog to Digital Converter. The temperature and time measurement at intervals is configurable in the Arduino source code. The SD card serves as a backup memory to store recorded values in a timestamp; in order to produce a sequence of events.

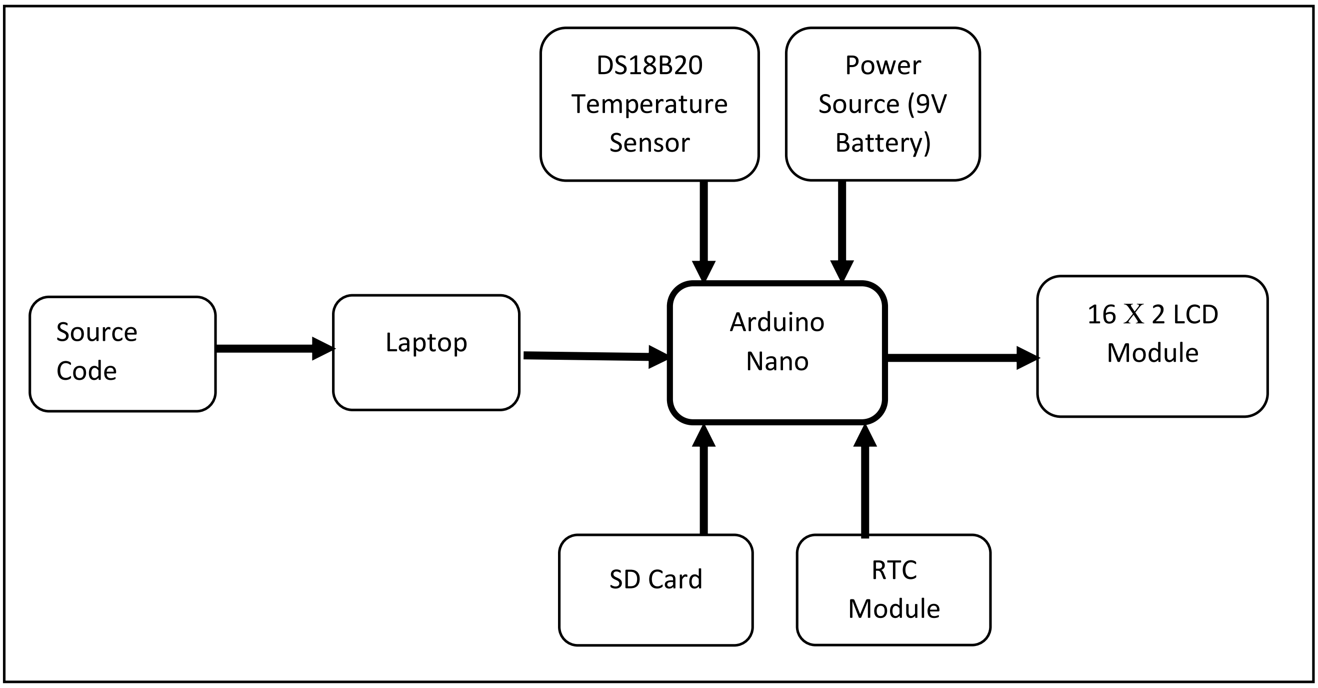

Figure 1: Block diagram of ATDL system design

Discussion of Components Required for Implementation

The components required for this framework can be categorized into major and minor components. The major components are Arduino Nano, 16x2 LCD module, DS3231 RTC module, DS18B20 Temperature sensor and an SD Card for backup. On the other hand, are minor components such as Light emitting diodes (LEDs), battery sources, voltage regulators, switches, jumpers and connecting wires. Following the use of these components is the software sub-system. An Arduino Integrated Development Environment (IDE) - software used to write, compile, upload and configure Arduino µCs with the aid of C++ programming language is required. This integrated environment shows the interaction between different pins, each analog and digital pins functions in the circuit and as well as how all the components in use, displays its working operation. Proteus design suite is important for simulation for testing and debugging circuits in real time before developing them into a physical model. The overall system flow of the proposed framework as indicated consists of three major design components and how they interface with the Arduino Nano is shown in three mini flow charts. A comprehensive process flow diagram of the proposed framework is further represented in Figure 2. There is a big gap in data and assessment of consumer food waste with respect to its quantity, quality and sources, but also regarding its associated costs, its social and environmental impacts. In literature, temperature is one of the fastest damages to agricultural products and eventually lead to wastage. With the help of a data logger especially that of temperature, agricultural wastes can be addressed to the barest minimum. However, the use of ATDLs in the area of agriculture has not been fully implemented yet and this work has contributed through the proposal of this friendly framework. In addition, the design approach employed in this work is to provide tactical solutions in curbing wastage of farm products during harvest and transportation of goods. It is worthy to note that; from the flow diagram all components are dependent on the operation of the Arduino Nano. The Arduino Nano is responsible for sending commands and signals to sensors. If the sensors are not active, functionality will be limited and the display provides feedback messages. A design of the proposed frame work is presented in Figure 3.

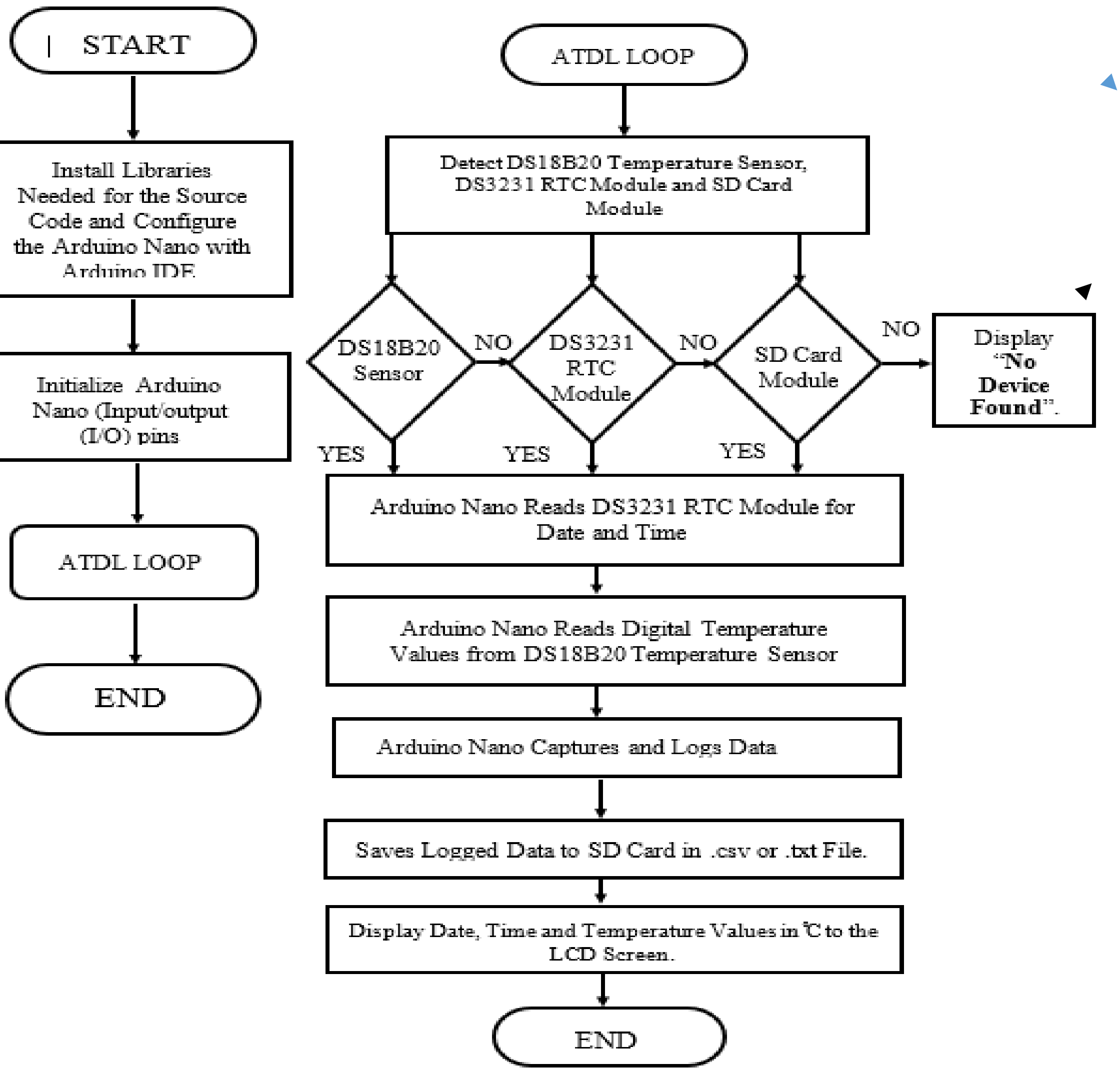

Figure 2: Process flow of the proposed Arduino Temperature data logger

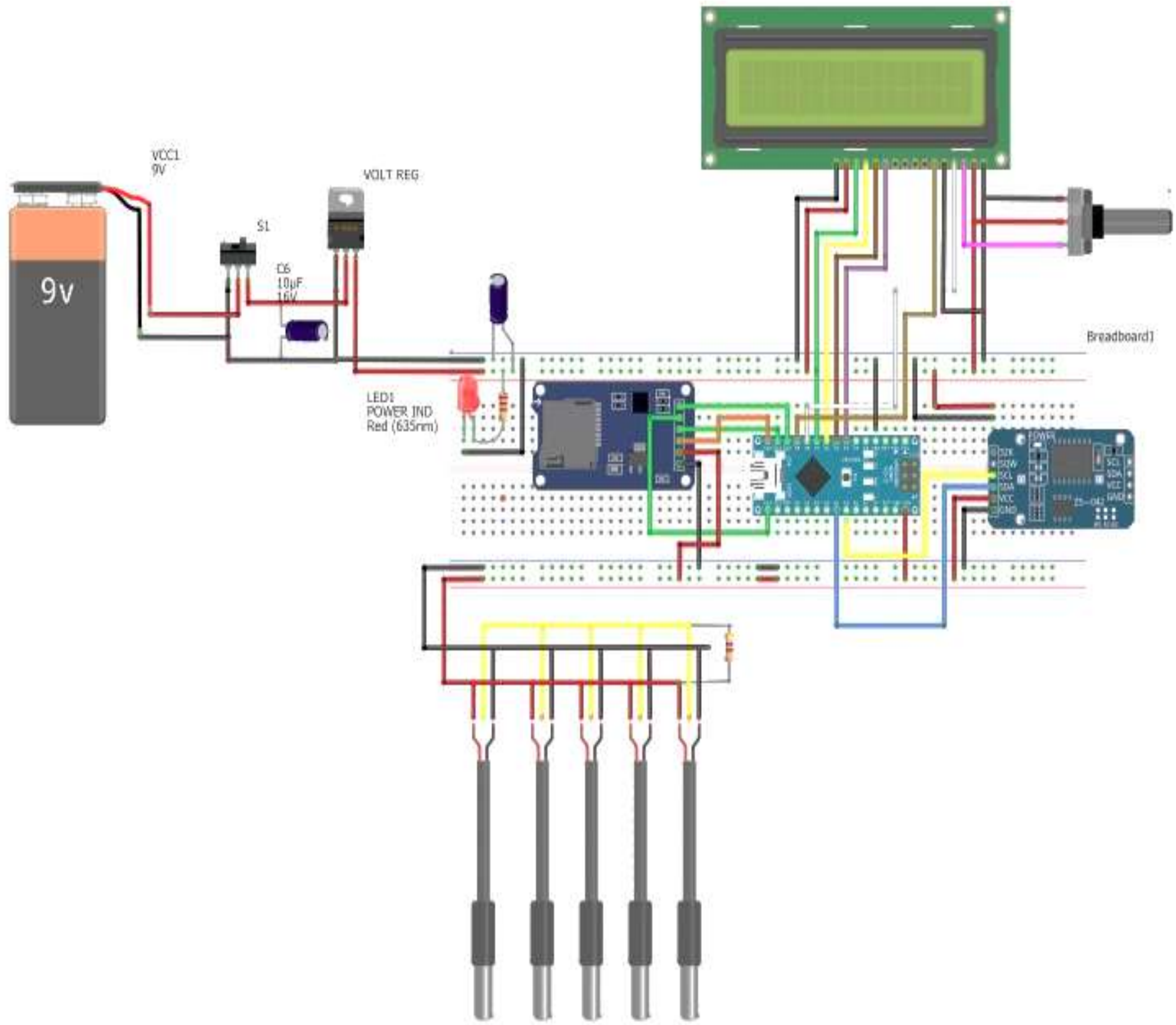

Figure 3: ATDL Prototype Design

Conclusion

The existence of DLs has provided solutions to environmental, ecological, health and agricultural related challenges across the globe. From the survey, it can be deduced that; the use of ATDLs in the area of agriculture has not been fully implemented yet and its utilization to solve problems as regards to minimizing food wastage require more innovations. This work has contributed to knowledge by using µC based solution to propose a cost-effective solution to food damages due to heat which can be deployed in a short period of time. In future a web application could be developed to reduce the complexity of analysis and provide precise indications of probable damage to farm products during transportation. More research can nonetheless be conducted to experiment and examine the proposed framework using top-down and bottom-up approaches that will complement each other in achieving the expected results. This can also be approached in future work through key players across different sectors. Additional field experience could also be gathered and analysed in line with other food-waste parameters beyond temperature considered in this research.

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Author Contributions

Methodology, Khadeejah A. ABDULSALAM, Oyinkansola B. OLUWASANJO and John A. ADEBISI; formal analysis, John A. ADEBISI; investigation, Oyinkansola B. OLUWASANJO and John A. Adebisi; resources, Khadeejah A. ABDULSALAM; writing—original draft preparation, Oyinkansola B. OLUWASANJO; writing—review and editing, John A. ADEBISI and Khadeejah A. ABDULSALAM, project administration, Khadeejah A. ABDULSALAM and John A. ADEBISI. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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