Design and development of a Microcontroller-Based Weight Measurement System for liquid Agriculture produce

Abstract

This research presents the development of a microcontroller-based weight measurement system tailored for liquid agricultural products. The system addresses the limitations of traditional manual weighing methods by incorporating a load cell, ADC, microcontroller, LCD, and Bluetooth module. The load cell converts weight into an electrical signal, processed by the microcontroller and displayed on the LCD. Calibration ensures accurate weight measurements. The system's portability, cost-effectiveness, and user-friendly interface make it a promising solution for agricultural applications. Quantitative aspects include the precise weight measurement enabled by the load cell and ADC, with calibration enhancing accuracy. Qualitative aspects encompass the system's ease of use, portability, and potential for integration into broader agricultural management systems. Future enhancements include additional sensors for comprehensive product analysis, cellular communication for remote data transmission, and data logging capabilities. This research contributes to the automation and efficiency of liquid weight measurement in agriculture, potentially improving resource utilization and crop yields.

Keywords: Load cell,Arduino Nano microcontroller, sensor integration, data logging

Introduction

The global agricultural sector faces a continuous challenge, meeting the growing demand for food while optimizing resource utilization. Accurate measurement of farming products is pivotal across the production cycle, impacting decisions from harvest estimation to post-harvest storage and transportation management. Traditional manual weighing methods, while prevalent, are often time-consuming, labor-intensive, and susceptible to human error. These limitations necessitate exploring innovative technologies to enhance efficiency and precision in agricultural measurement practices(Fitzgerald *et al.*, 2015).

This research presents the design and development of a novel microcontroller-based weight measurement systemspecifically designed for liquid products. This system addresses the shortcomings of traditional methods by leveraging a load cell as its core sensing element. The load cell functions as a transducer, converting the applied weight of an agricultural product into a measurable electrical signal. This signal is then acquired and processed by a microcontroller for further analysis and presentation. It also meticulously dissects the system's hardware architecture, explaining the functionalities of each crucial component. Besides, itdelves into the principles behind the load cell's operation and its role in weight conversion. The research further explores the significance of the Analog-to-Digital Converter (ADC) in transforming the analog signal into a digital format suitable for microcontroller processing.The microcontroller is the system's brain, coordinating communication between various components and executing programmed instructions. In addition, the functionalities of the chosen microcontroller are emphasized, highlighting its role in data acquisition, processing, and control and examining the integration of an LCD for user-friendly weight visualization and a Bluetooth module for potential wireless data transmission capabilities.

The significance of this research lies in its contribution to the automation and efficiency of liquid weight measurement tasks within the agricultural sector. This portable, cost-effective, and user-friendly system offers a promising solution for agricultural professionals seeking to streamline weight determination processes. Furthermore, the paper explores potential future advancements for the system, including integrating additional sensors for comprehensive product analysis, incorporating cellular communication technologies for remote data transmission, and implementing data logging capabilities for long-term trend analysis. These enhancements pave the way for the development of a comprehensive agricultural monitoring system capable of data acquisition, analysis, and automation, ultimately leading to improved agriculture practices, optimized resource utilization, and potentially, increased crop yields.This research strives to bridge the gap between traditional, labor-intensive methods and the need for precise, automated measurement solutions in the agricultural sector.

Components and system design

1. Weighing transducers (Load cell)

Weight transducers, also known as weight sensors, are a type of force transducer that convert applied mechanical forces (weight, load, tension, compression, or pressure) into a measurable electrical signal (Figure 1). This conversion principle allows for the quantification and analysis of various forces. As the applied force increases, the electrical output signal exhibits a proportional change, enabling accurate weight measurement(Gaikwad and Dahikar, 2013). In addition, the structural core of a weight transducer is a metal body (flexure) typically constructed from high-strength materials like aluminum or stainless steel. This material selection offers two key advantages: Structural Rigidity; The material's inherent strength allows the transducer to withstand significant loads without mechanical failure, and Elastic Recoverability; The material exhibits a degree of elasticity, enabling it to deform minimally under load and return to its original shape upon force removal. This elasticity ensures accurate and repeatable measurements. This research uses a 20 kg load cell for weight measurement thatis ubiquitous in electronic weighing scales, owing to their exceptional accuracy in liquid weight determination. They function by translating a specific mechanical force (often weight) into an electrical output signal. This signal is transmitted through a load cable to the scale's display unit, allowing the operator to visualize the precise weight reading.

2. Analogue to Digital Convertor (ADC)

Microcontrollers are often employed in weight measurement systems as shown in figure 1. These devices typically include internal ADCs for converting analog signals (e.g., voltage) from sensors into digital data for processing. Alternatively, external ADCs can be interfaced with microcontrollers to enhance functionality(Gaikwad and Dahikar, 2013).This research uses the HX711, a high-precision 24-bit ADC specifically designed for applications involving weighing scales and industrial control systems.This ADC integrates seamlessly with bridge sensors, a common type of weight sensor. The HX711 features an on-chip programmable gain amplifier (PGA) that offers selectable gain options (32, 64, and 128) to amplify weak load cell signals before conversion to digital format.The Grove - ADC for Load Cell (HX711) module offers a convenient solution for load cell integration. It encompasses the HX711 ADC and provides additional functionalities. Notably, it includes a low-noise programmable amplifier for signal conditioning(Das *et al.*, 2019).

3. Micro-controller

Embedded systems often rely on microcontrollers (MCUs) to execute specific control tasks. These compact integrated circuits typically integrate a processor, memory elements, and programmable input/output (I/O) peripherals on a single chip. This design philosophy minimizes size and cost, making them ideal for various applications requiring dedicated control functionalities. MCUs find applications in controlling machines, data acquisition from sensors, and automating processes within embedded systems. Current research utilized the Atmel ATmega328P, an 8-bit AVR microcontroller known for its high performance and low power consumption (Figure 1). This MCU boasts a single-cycle execution capability for a comprehensive instruction set, enabling efficient program execution. Notably, the ATmega328P serves as the core processor for popular development boards like Arduino Uno and Arduino Fio(Ogunbiyi *et al.*, 2023).

The Atmel ATmega328P operates up to 20 MHz frequency and features 23 I/O pins, including 6 that are capable of pulse width modulation (PWM) output. For memory, the ATmega328P offers 32 KB of flash memory for program storage, 2 KB of SRAM for data manipulation, and 1 KB of EEPROM for non-volatile data storage. The MCU is housed in a DIP-28 package and can operate on a voltage range of 1.8 V to 5.5 V. The ATmega328P is equipped with a versatile peripheral set to support a wide range of embedded system design requirements. It provides 14 digital I/O pins for general-purpose control applications. Additionally, six of these pins offer pulse width modulation (PWM) outputs, enabling flexible control of analog devices by varying their duty cycle. For analog signal acquisition, the MCU integrates six dedicated analog input channels. A built-in Micro USB port simplifies both in-system programming (ISP) and power supply, streamlining development and deployment workflows. The inclusion of three onboard Grove connectors expedites prototyping by providing standardized connections to various Grove modules. Finally, the selectable system voltage operation (3.3 V or 5 V) enhances the MCU's compatibility with a broader spectrum of components within an embedded system design.

4. LCD

Liquid Crystal Displays (LCDs) are a prevalent technology for flat-panel displays, known for their thin profile and low power consumption. They function by manipulating liquid crystals to control light transmission and generate visible images. These crystals are sandwiched between polarizing filters and electrodes within the display structure, and a backlight illuminates the panel for enhanced visibility(Noor *et al.*, 2012).

Our research employed a common variant, the 16x2 LCD as shown in figure 1. This alphanumeric display offers a character resolution of 16 columns by 2 rows, making it suitable for presenting text and basic symbols. Its widespread adoption stems from its versatility and ease of use, making it a fixture in various electronic devices like calculators, digital clocks, and measurement instruments. The display module typically operates within a voltage range of 4.7V to 5.3V and exhibits a low current consumption of approximately 1mA (excluding backlight illumination). This module offers a display resolution of 16 characters per line across 2 lines, totaling 32 alphanumeric characters. Notably, it possesses the capability to render custom characters in addition to standard characters and can function in both 8-bit and 4-bit data transfer modes(Rikame and Kulkarni, 2014).

5. Bluetooth module

The Internet of Things (IoT) heavily relies on short-range wireless communication technologies for data exchange between devices. Bluetooth Low Energy (BLE) is a popular choice due to its standardized protocols and low power consumption. This communication is facilitated by Bluetooth modules, and compact PCBA boards housing integrated Bluetooth functionalities.

This research incorporated the HC-05 Bluetooth module as shown in figure 1, specifically designed for establishing transparent wireless serial connections. This module functions according to the Bluetooth Serial Port Profile (SPP), enabling data exchange between devices using a familiar serial communication protocol. The HC-05 features an integrated antenna for simplified integration, eliminating the need for separate antenna components. It operates within the 2.4 GHz Industrial, Scientific, and Medical (ISM) band, adhering to common wireless communication regulations. Additionally, the HC-05 offers Programmable Input/Output (PIO) control, allowing for customized behavior through dedicated control pins. This feature enhances the module's flexibility in various applications. Furthermore, the HC-05 can operate in either master or slave mode, providing adaptability within network configurations(Mehta *et al.*, 2018). In our project, the HC-05 functioned in slave mode, acting as a controlled device within the Bluetooth network.

6. DC-DC buck converter

Direct current (DC) to DC converters play a pivotal role in regulating power within electronic systems. These devices transform a source of DC voltage from one level to another, catering to the diverse power requirements of various components. Essentially, they neither store nor generate electrical energy but facilitate the conversion between voltage levels. Within the automotive industry, DC-DC converters serve as essential intermediaries, harmonizing the operation of systems operating at different voltage levels(Thaveedu*et al.*, 2020).

This research project employed the LM2596, a widely used DC-DC buck converter manufactured by Texas Instruments. The LM2596 series comprises monolithic integrated circuits specifically designed for buck (step-down) switching regulator applications. These regulators are capable of driving a 3A load with exceptional line and load regulation characteristics, ensuring consistent voltage output even when input voltage or load current fluctuates(Alsumady*et al.*, 2021).The adjustable variant of the LM2596 boasts a wide input voltage range, functioning effectively with input voltages between 4.5V and 40V. This flexibility allows it to convert incoming voltage to a user-defined output voltage while maintaining a continuous current output of up to 3 amps. The LM2596 series operates at a switching frequency of 150 kHz. This higher switching frequency offers a significant advantage: it permits the utilization of smaller filter components compared to those required with lower frequency switching regulators. This translates to a more compact overall circuit design. The LM2596 is available in two standard package options: a 5-pin TO-220 through-hole package with various lead bend configurations and a 5-pin TO-263 surface mount package, catering to different space constraints within a PCB layout.

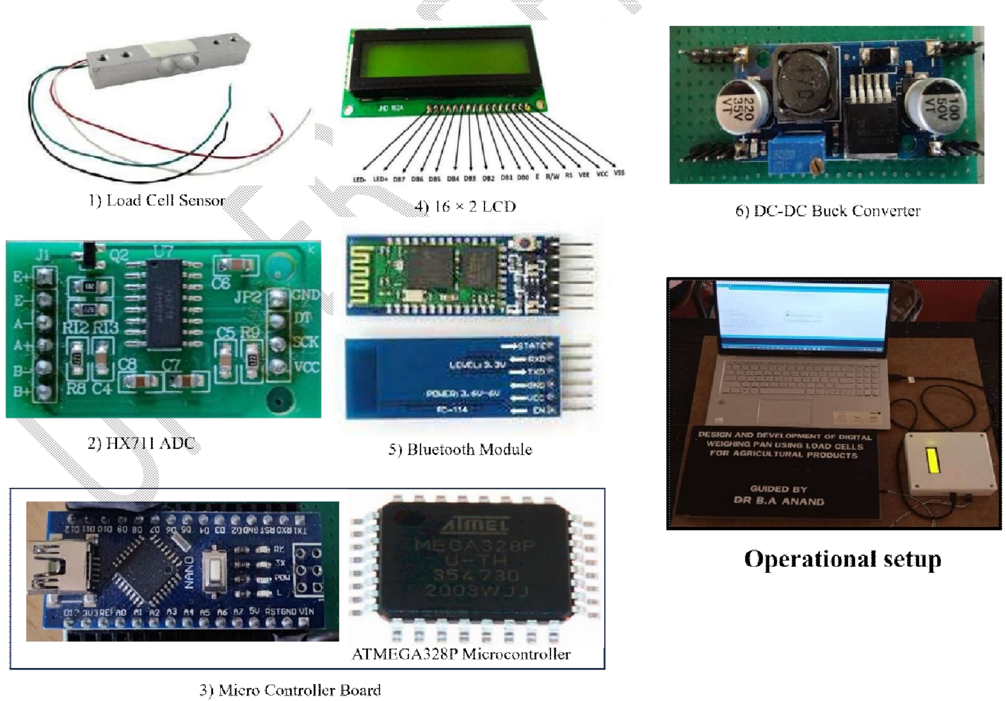

Figure 1: Components and operational setup of Microcontroller-Based Weight Measurement System for liquid Agriculture produce

Proposed system design

The proposed system design establishes physical connections between the system's components as shown in Figure 2. This crucial step involves connecting the LCD board to the load cell board, ensuring proper communication for data exchange. Subsequently, both boards are connected to a power supply, typically a laptop in this case, to provide the necessary operating voltage. Later, the Arduino software development environment plays a vital role in configuring and controlling the microcontroller. Within this environment, the appropriate communication port settings are verified. This step ensures seamless communication between the Arduino software and the microcontroller on the load cell board. Then the LCD board is powered on, allowing for initial system activation. Following this, the program containing the weight measurement and display logic is uploaded to the microcontroller on the load cell board. This program instructs the microcontroller to process weight data from the load cell and display it on the LCD.Besides, tare weight calibration is essential to ensure accurate weight measurement for the target liquid product. This process accounts for the weight of the empty container placed on the load cell platform. The empty container is placed on the platform, and the LCD is then powered off and powered on again. This sequence effectively sets the empty container's weight as the baseline (tare weight). Any subsequent weight measurements will reflect the weight of the liquid product placed on the load cell platform after tare weight calibration. Finally, the product intended for weight measurement is carefully placed on the load cell platform. The microcontroller processes the weight data received from the load cell and converts it into a relevant unit. The processed liquid weight value is then presented on the LCD screen for easy visualization.

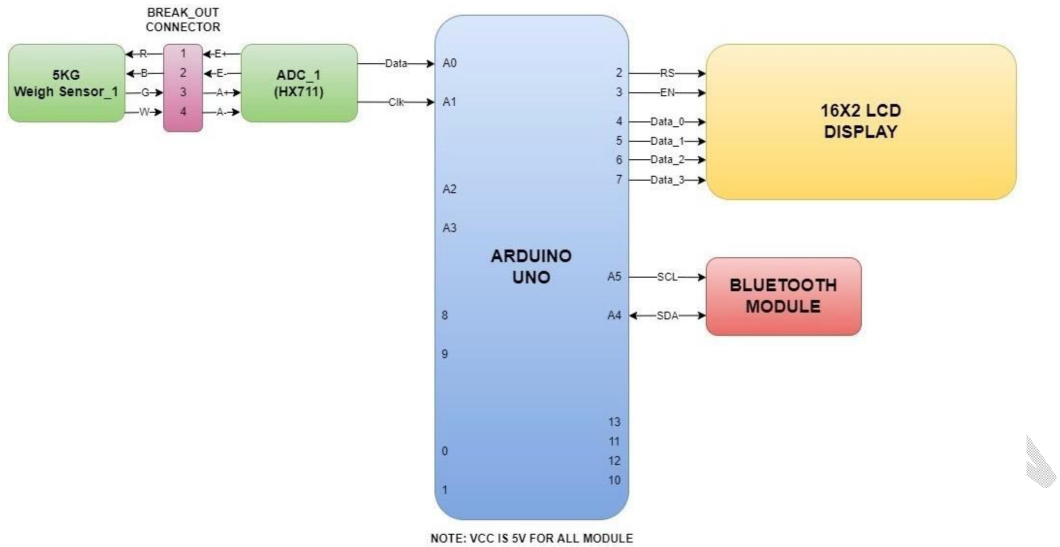

Figure 2: Block diagram of the proposed system

Algorithm

This section details the operational flow of a microcontroller-based system designed to measure the weight of liquid agricultural products (Figure 3). The system leverages a load cell to convert applied weight into an analog electrical signal.This signal is then acquired by the microcontroller through its analog input pin.A crucial step involves converting the analog signal into a digital value suitable for processing by the microcontroller. This conversion is achieved using the on-board Analog-to-Digital Converter (ADC). The raw digital data obtained from the ADC might necessitate calibration and scaling to compensate for inherent sensor non-linearities and transform the value into a meaningful unit (e.g., grams, kilograms).To ensure system autonomy, the voltage of the Li-ion battery powering the system is monitored using the ADC. This allows for tracking the battery's health and preventing unexpected power disruptions.The processed digital data, representing the weight of the liquidproduct, can then be utilized for various application-specific calculations, comparisons, or triggering actions based on predefined weight thresholds. Finally, the processed weight data is presented in a user-friendly format, such as displaying it on an LCD screen. The system can be optionally expanded to include a Bluetooth module for wireless data transmission.The entire process operates within a continuous loop, enabling the system to constantly monitor the load cell readings and measure the weight of various liquid products placed on the sensor. This continuous monitoring capability makes the system suitable for a range of agricultural applications requiring weight measurement.

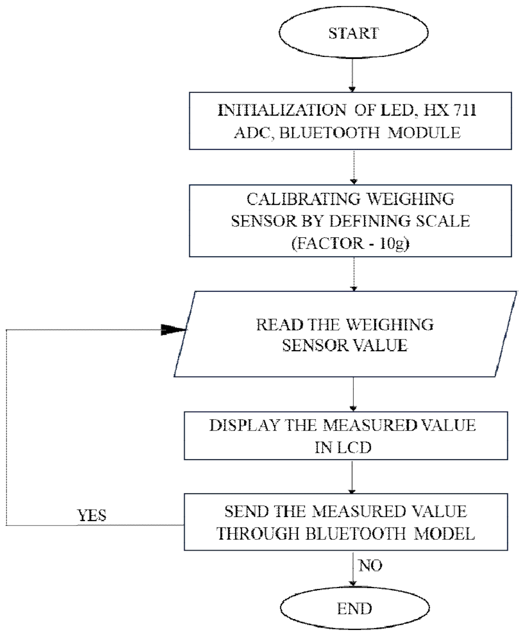

Figure 3: Operational flow of a microcontroller-based system designed to measure the weight of liquid agricultural products

Functionalities of circuit

1. Signal Amplification with the HX711

The HX711 amplifier plays a crucial role in amplifying the weak signal received from the battery voltage. This highly precise 24-bit analog-to-digital converter (ADC) is specifically designed for applications in weigh scales and industrial control systems(Sushmitha and Kumar, 2020).The HX711 features two differential analog inputs that connect directly to the sensor (load cell/battery). It provides stable amplification with minimal noise, significantly improving the signal quality. The amplified analog signal is then converted into a digital format by the internal sigma-delta modulator and transmitted to the microcontroller through a serial interface (SPI).Furthermore, the HX711 incorporates a programmable digital filter to eliminate unwanted noise and a tare function that enables automatic zeroing of the load cell when no weight is applied. This chip operates with a supply voltage ranging from 2.7V to 5.5V and boasts a low power consumption of less than 1mA. The HX711's versatility and precision in handling small electrical signals from sensors and load cells make it a valuable asset in various applications, including weighing scales, force sensors, and strain gauges(Kanade *et al*., 2023)

2. The Arduino Nano: System Brains and Control Center

The project utilizes an Arduino Nano, a microcontroller board powered by the ATmega328P microcontroller. Programmed using the Arduino IDE, this microcontroller acts as the system's brain, coordinating communication between input and output pins. The Nano offers a total of 14 digital input/output pins (PWM capable on 6) and 8 analog input pins for interfacing with various sensors and electronic components.The ATmega328P microcontroller, a popular choice in various electronic devices, is based on the AVR RISC architecture(Šipoš and Šimoňák, 2020). This Harvard architecture separates program and data memory, providing 32KB of flash memory for program storage, 2KB of SRAM for temporary data storage, and 1KB of EEPROM for non-volatile data storage. It also features 23 general-purpose I/O pins for digital input/output, analog input, and PWM output functionalities.

The microcontroller executes instructions stored in its program memory. These instructions, written in assembly language or high-level languages like C and compiled into machine code, are then processed by the central processing unit (CPU) in a fetch-decode-execute cycle. The ATmega328P boasts a wide range of peripherals for external world interaction. The Arduino community has developed a rich library of pre-written code for common tasks, simplifying the programming process for tasks like sensor data acquisition and motor control(Turley *et al.*, 2015).

In the current research, the Arduino Nano is programmed to read the amplified battery voltage signal from the HX711. A calibration factor is then applied to convert the signal into a weight reading. The Arduino IDE facilitates code writing and uploads to the Nano, enabling various functionalities from sensor data acquisition to output control using motors and other electronic components(Kondaveeti *et al.*, 2021). Calibration is a crucial step before weight sensor operation. This process involves applying known weights to the load cell and recording the corresponding readings. These readings are then used to calculate a calibration factor that translates the signal into accurate weight measurements. For this specific model, a calibration factor of -10g was determined.

3. Load Cell Principle and Signal Processing:

Load cells function as transducers, converting applied physical force (load) into a measurable electrical signal and thisprinciple hinges on the concept of strain gauge measurement(Qandil and Zaid, 2015).Strain gauges are integrated within the load cell and their electrical resistance changes in response to mechanical strain or deformation. When a load is applied to the load cell, it experiences mechanical deformation. This deformation alters the resistance of the strain gauges, typically through compression or expansion.The load cell incorporates these strain gauges within a Wheatstone bridge configuration. A Wheatstone bridge comprises four resistive elements, and the change in strain gauge resistance disrupts the bridge's balance. This imbalance generates a small differential voltage signal across the bridge, with the magnitude directly proportional to the applied force or load.However, the raw voltage signal from the load cell is typically weak and requires further processing for accurate measurement. An instrumentation amplifier or dedicated signal conditioning circuitry amplifies and conditions this signal, ensuring its suitability for subsequent processing and measurement(Quintáns*et al*., 2006).

4. Calibration for Accurate Weight Measurement

Before utilizing the load cell, a crucial calibration step is required. This involves applying known weights and meticulously recording the corresponding output readings. This calibration process establishes a precise relationship between the output signal and the actual weight, enabling accurate weight measurements in subsequent applications.

5. Weight Display and Data Transmission

The weight data obtained from the load cell can be displayed or transmitted using various methods. This research utilized a 16x2 liquid crystal display (LCD) and an HC-05 Bluetooth module for data visualization and the potential for wireless transmission. The 16x2 LCD is an alphanumeric display capable of presenting 16 characters per row across its two rows. Due to its versatility and user-friendliness, it finds widespread application in numerous electronic devices like calculators, digital clocks, and various measurement instruments(Rathod *et al.*, 2023).The display operates under the control of a dedicated controller chip, typically an HD44780. This chip receives data from the microcontroller or another source and translates it into signals that govern the display. The 16x2 LCD boasts a backlight for enhanced readability in low-light environments(Cha and Lee, 2024).

HC-05 Bluetooth Moduleis a popular module facilitating wireless communication between devices by adhering to the Bluetooth Serial Port Profile (SPP). This profile offers a simplified method for establishing a wireless communication link between two devices(Faiqurahman*et al.*, 2019).The HC-05 module functions as a slave device, readily pairing with any master device such as a smartphone or computer(Samasgikar, 2013). It utilizes a UART interface for communication with the host microcontroller, which transmits and receives data using AT commands. Configuration and connection establishment with the master device is achieved by the host microcontroller sending AT commands to the HC-05 module. Once connected, the module can transmit and receive data wirelessly.This module offers a range of up to 10 meters and operates within the 2.4 GHz ISM frequency band. Additionally, it supports a variety of baud rates ranging from 1,200 to 115,200 bps(Suresh *et al.*, 2019).

Conclusion

This research has successfully developed a microcontroller-based weight measurement system tailored for liquid agricultural products. By addressing the limitations of traditional manual weighing methods, this system offers a robust, efficient, and accurate solution for the agricultural sector. The integration of a load cell, ADC, microcontroller, LCD, and Bluetooth module has resulted in a portable, cost-effective, and user-friendly device.

The system's ability to convert analog weight signals into digital data for processing and display demonstrates its potential to streamline agricultural operations. The inclusion of a Bluetooth module paves the way for future integration with larger agricultural data management systems.

A key advantage of this research lies in its potential to enhance agricultural productivity and efficiency. By providing precise and real-time weight measurements, farmers can optimize resource allocation, reduce wastage, and improve overall yield. Moreover, the system's portability and ease of use make it a practical tool for various agricultural applications.

In conclusion, this research presents a promising step towards modernizing agricultural practices through the development of a reliable and efficient weight measurement system. By bridging the gap between traditional methods and technological advancements, this system has the potential to transform agricultural operations and contribute to sustainable food production.

Future perspective

While this research establishes a functional prototype, there exists significant potential for future advancements:

Sensor Integration; The system can be expanded to incorporate additional sensors for comprehensive agricultural product analysis. Examples include moisture sensors for measuring water content and temperature sensors for monitoring product temperature during storage or transportation.

Wireless Data Transmission; The HC-05 Bluetooth module offers a limited transmission range. Future iterations could integrate cellular communication technologies like GSM or NB-IoT for remote data transmission and monitoring. This would enable farmers to access weight and potentially other sensor data from their agricultural fields remotely, facilitating informed decision-making.

Data Logging and Analysis; Integrating an SD card or flash memory module would allow the system to record weight and sensor data over time. This data could then be uploaded to the cloud for analysis using agricultural data platforms. This analysis could identify trends, predict harvest yields, and optimize storage conditions.

Machine Learning Integration;By incorporating machine learning algorithms on the microcontroller or a connected device, the system could be trained to classify different agricultural products based on weight and potentially other sensor readings. This would enable automated sorting of produce into different categories.

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Details of the AI usage are given below:

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