Cassava Starch Measurement in the Field - Evolution of a Low Cost Test Instrument with Wireless Connectivity

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***Abstract*—The evolution in design philosophy for a portable test instrument for estimating the starch content of cassava roots is described. The instrument uses a radio frequency reflectometry technique to measure return loss using a coaxial probe. An on-board microprocessor then determines the starch content of the cassava sample based on a pre-stored calibration table. The design evolution started with a minimum viable hardware platform that was used for proof of concept and to gather preliminary field data. The next generation added wireless connectivity for cloud data collection and analysis, user interface improvements and rechargeable battery capability. Design focus then shifted to cost reduction, robustness and suitability for mass production so that the instrument can be put into the hands of farmers.**

***Index Terms*—Food Technology, Food Sustainability, Reflectometer, IoT, PSoC**

I. Introduction

Cassava (Manihot Esculenta) is a tropical root vegetable which is one of the most important starch crops globally [?] and primary food staple in sub-Saharan Africa. The authors have previously established a method of determining the starch content of cassava roots, using a Radio Frequency (RF) reflectometry technique [?], which involves measuring the S_{11} reflection parameter using a coaxial probe inserted into the cassava root sample. The method centres on the measurement of return loss [?], which is a function of the the complex impedance (S_{11}) presented to the probe by the cassava root material. Return loss values were shown to be related to to starch content in [?]. Impedance measurement of crops, albeit at lower frequencies, has also been used to assess the ripeness and to classify fruits as in [?] and [?], respectively. Another publication describes a simple, low cost, hand-held test instrument employing the return loss method, that could potentially enable farmers to test starch content of cassava roots quickly and non-destructively in the field [?]. This "version 1" instrument was shown to be effective in field tests carried out at the International Institute of Tropical Agriculture (IITA) in Nigeria (https://www.iita.org). Since the concept was thus proven, the focus of the project shifted to making an instrument that was more capable, internet ready and suitable for mass production at a lower cost. This paper describes the evolution of the instrument from the original version 1 through to the current version 3 and the design choices and trade-offs involved.

II. Motivation and Design Goals

The motivation for the developments described in this paper was to evolve the hardware towards a robust, low cost instrument that could be mass produced and distributed to farmers in several African countries, starting with Nigeria, with the goal of contributing to a wider effort to improve productivity and farm incomes in the cassava sector. The addition of Wireless connectivity, via Bluetooth, to enable mass data collection and analysis, was critical to achieving this goal.

III. Product Evolution

A. Hardware evolution

Three different versions of the instrument were developed, which reflect the evolution from a basic proof-of-concept demonstrator towards a commercially viable, fully featured product. All versions comprised four basic elements: a simple reflectometer, an RF signal source (frequency synthesizer), a low-cost microprocessor and a display.

B. Version 1

The first generation of hardware was the minimum viable platform intended to prove the concept of a battery operated portable instrument to measure starch content of cassava using the RF return loss method. The architecture of this instrument was described in [?] and consisted of an RF signal source (frequency synthesiser), a reflectometer (to measure RF power reflected from the cassava sample), some simple data processing and a display. In version 1 the display was simply an array of 5 LEDs to indicate a range of return loss values calibrated to represent starch content in 5 bands, from low to high. The processor used was an ATmega328 in the form of an Arduino nano module [?].

The version 1 hardware is shown in Fig. 1 and a summary of the version 3 features is given in Table I. The probes used in all three hardware versions consisted of a rigid coaxial probe connected to the instrument via the SMA connector (at the left edge in Fig. 1). The probes are described in [?]. The Arduino

Nano was an excellent choice for this version as it allowed rapid software development and iteration. On the other hand, the limited processing power of the Arduino Nano, and the need for wireless connectivity meant that, once the concept had been proven, we moved quickly on to the version 2 hardware.

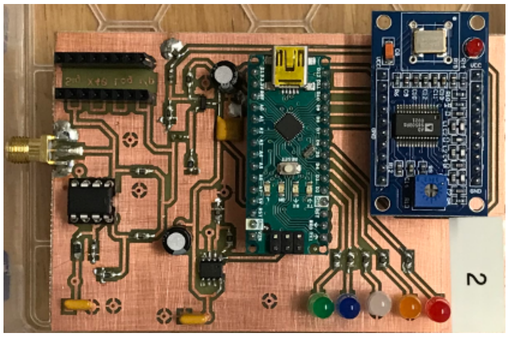

Fig. 1: Version 1 hardware

TABLE I: Version 1 Features

Design goals	• Proof of concept (RF reflectometry measurement to determine starch content). • Prove the feasibility of low cost, portable data collection in the field.
Processor	Arduino nano (ATmega328).
User Interface	5 LED bar-graph for starch level indication.
Connectivity	None.
Power supply	4 X AA battery

C. Version 2

The version 2 hardware was based to the Heltec processor module [**?**], which has a more powerful ESP32 processor and incorporates a built-in OLED display. This version was a significant improvement over the previous version as it provided more processing power and the OLED display allowed direct presentation of reflectometer readings and starch values. Another major enhancement in this version was the addition of Bluetooth connectivity, allowing data to be uploaded to the internet via a mobile phone. We were able to demonstrate data from the version 2 units being sent via Bluetooth to the mobile phone app and then onwards to the cloud, along with geolocation and timestamp information. A temperature sensor was added in version 2 to allow probe temperature to be recorded and added the dataset of starch readings. The version 2 hardware is shown in Fig. 2 and a summary of the version 2 features is given in Table II.

Another evolution in Version 2 was towards rechargeable battery supply, with built-in battery charging via a standard micro USB connector, and power management circuitry to supply a standard 5V supply to the electronics irrespective of the state of the battery. Other enhancements were added in version 2 which were later found not to be useful and were removed in version 3, such as a removable SD card for data storage and 5 data entry keys. Since we developed the version 2 hardware, the Heltec ESP32 product is no longer recommended for new designs. Anticipating end-of-life for this component, we embarked on development of the version 3 hardware.

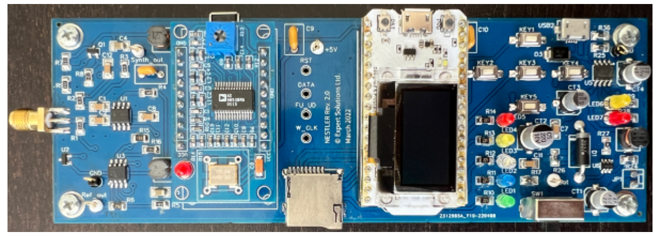

Fig. 2: Version 2 hardware

TABLE II: Version 2 Features

Design goals	• Wireless connectivity. • Improved user interface (OLED display). • Probe temperature measurement. • Improved power supply economy and reliability (internal rechargeable Li-ion battery, USB charging).
Processor	ESP32/Heltec
User Interface	5 LED bar-graph starch level indication. OLED display. 5 input keys.
Connectivity	Bluetooth (BLE). Micro SD card backup data storage.
Power supply	Integral Li-Ion battery with USB charging.

D. Version 3

The version 3 hardware was based around the Cypress PSoC 6 processor, [**?**], which allowed a higher level of integration at a lower cost. The Cypress PSoC 6 contains dual core CPUs (ARM Cortex-M4 plus ARM Cortex-M0) together with mixed-signal arrays of configurable integrated analog and digital peripherals. This allowed us to simplify the external circuitry by, for example, implementing the main signal generator internally to the PSoC at 6MHz, which was then multiplied up to 30 MHz using an external frequency multiplier. This replaced the expensive frequency synthesiser used in previous versions. The PSoC module used in version 3 (CYBLE-416045-02) incorporates a built-in BLE radio and other features that were helpful for mass production, such as UUID generation for BLE. An internal real-time-clock allows data readings to be time-stamped in the instrument itself (not in the mobile phone, as with version 2), allowing offline data collection. Whereas the version 2 display was built into the Heltec processor module, in version 3, the OLED display was a separate module, connected to the main board via a 5 pin connector, thus allowing other types of display to be used. The version 3 board is shown in Fig. 3. For simplicity, the number of buttons was reduced to only one ”test” button on the side of the instrument.

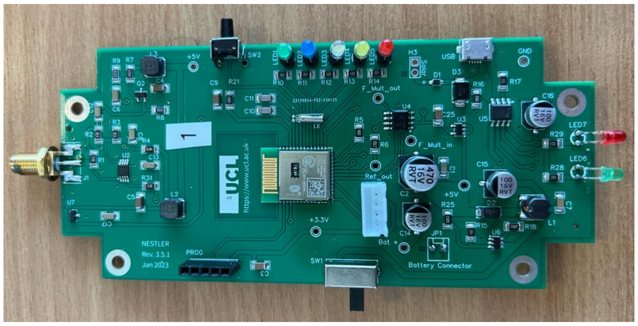

Fig. 3: Version 3 hardware

Since the PSoC processor runs of 3.3V, an additional 3.3V linear regulator needed to be added to the power management circuitry, which was otherwise unchanged from version 2. An option to allow battery charging from a solar cell was also added in version 3. A summary of the version 3 features is given in Table III.

TABLE III: Version 3 Features

Design goals	• Cost reduction through higher integration and lower component count. • Allow for different display options. • Extended product lifetime and better Better support. • Solar battery charging.
Processor	Cypress PSoC
User Interface	5 LED bar-graph starch level indication. OLED display. 1 input key.
Connectivity	Bluetooth (BLE).
Power supply	Integral Li-Ion battery with USB charging and solar charge controller.

E. Software

Although three different processor and hardware platforms have been used so far, the core software algorithm has remained basically the same. The logic is outlined in Fig. 4.

IV. Conclusion and Next Steps

This paper outlines the evolution in design philosophy for a portable test instrument for estimating the starch content of cassava roots. The development aimed to create a cost effective solution, which is easy to use and can provide short range wireless connectivity for data upload. The instrument reported here will become part of a larger ecosystem for monitoring the health and yield of Cassava. The hardware is due to be field tested in Nigeria within the coming months. Once performance and utility are proven the next step in hardware evolution will be on design for mass production, with a focus on cost reduction and robustness (IP66 enclosures etc.).

V. Acknowledgement

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```
begin
    Establish BLE connection and initialise services;
    Set all LEDs to 0 state;
    while 1 do
        Scan test button;
        if Button_pressed then
            Set all LEDs to 0 state;
            Chip enable reflectometer and signal generator;
            Read Reflectometer_value and calculate
              Starch_content;
            Read Temperature_value;
            Update readings on OLED display;
            switch Starch_content do
                case ≤ 5% do
                    Set Red LED to 1 state;
                case > 5% ∧ ≤ 10% do
                    Set Amber LED to 1 state;
                case > 10% ∧ ≤ 15% do
                    Set White LED to 1 state;
                case > 15% ∧ ≤ 20% do
                    Set Blue LED to 1 state;
                case > 20% do
                    Set Green LED to 1 state;
                end
            end
            Transmit measured data over BLE;
        else
            Enter null values on OLED display;
        end
    end
end
```

Fig. 4: Software Algorithm

References

[1] N. K. Van Alfen, *Encyclopedia of agriculture and food systems*. Elsevier, 2014.

[2] T. Odedeyi, I. Rabbi, C. Poole, and I. Darwazeh, "Estimation of starch content in cassava based on coefficient of reflection measurement," *Frontiers in Food Science and Technology*, vol. 2, p. 878023, 2022.

[3] C. Poole and I. Darwazeh, *Microwave Active Circuit Analysis and Design*. Elsevier Science, 2015.

[4] P. Ibba, A. Falco, B. D. Abera, G. Cantarella, L. Petti, and P. Lugli, "Bio-impedance and circuit parameters: An analysis for tracking fruit ripening," *Postharvest Biology and Technology*, vol. 159, p. 110978, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0925521419304983

[5] P. Ibba, C. Tronstad, R. Moscetti, T. Mimmo, G. Cantarella, L. Petti, Ø. G. Martinsen, S. Cesco, and P. Lugli, "Supervised binary classification methods for strawberry ripeness discrimination from bioimpedance data," *Scientific Reports*, vol. 11, no. 1, p. 11202, 2021. [Online]. Available: https://doi.org/10.1038/s41598-021-90471-5

[6] T. Odedeyi, C. Poole, X. Liu, A. Kassem, G. Oyebode, R. Ismail, and I. Darwazeh, "A low-cost instrument for estimating the starch content of cassava roots based on the measurement of rf return loss," in *2020 IEEE International Symposium on Circuits and Systems (ISCAS)*, 2020, pp. 1–5.

[7] Arduino S.r.l. Arduino Nano. [Online]. Available: https://store.arduino.cc/products/arduino-nano

[8] Heltec Automation. WiFi Kit 32 (V3). [Online]. Available: https://heltec.org/project/wifi-kit-32-v3/

[9] Cypress Semiconductor. PSoC 62 Datasheet. [Online]. Available: https://www.infineon.com/dgdl/Infineon-PSoC_6_MCU_CY8C62x6_CY8C62x7-DataSheet-v14_00-EN.pdf