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NOVEL TECHNIQUES FOR FOOD TRACEABILITY SYSTEM

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Abstract

Food traceability is important for food control according EU Regulation. Implementing real-time food traceability requires the use of novel networking solutions and computer embedded systems. This paper introduces a new technique for active food traceability based on energy-efficient wireless sensor networks - Long Range Wide Area Networking (LoRaWAN) technology.

Our network infrastructure is for active food traceability based on existing Internet of Things technologies. LoRa is used as technology for communication due to the fact that its end nodes allow secure communication up to 5 km in urban area. A model for a modern infrastructure for food traceability has been developed.

Based on the proposed model for network infrastructure for active food traceability a block diagram of such a traceability system has been synthesized. The main modules of our food traceability system include LoRa end node, Lora gateway, The Things Network, application server, router and mobile device. Special attention has been paid to the selection and the design of our LoRa sensor end node for food traceability by using modern microcontroller ATmega32u4, RN2483 transmitter, TCS34725 colour sensor and BME280 environmental sensor. An exemplary use of our end module for food traceability is active monitoring of meat products. The schematics and algorithmic diagram of the designed food traceability sensor end node are given. We have developed a web application in Python for real-time monitoring of meat products during storage sensor data like temperature, colour and humidity. The flowchart diagram of our web application for active food traceability is given. A graphical user interface for monitoring of technological parameters temperature (from -20 ^{0}C to +40 ^{0}C), relative humidity (from 0 to 100%), lighting (from 0 to 100%) and colour (R = 0 - 255, G = 0 - 255, G = 0 - 255) is proposed.

The proposed system is open hardware and software and allows expansion with different types of sensors and dashboards. The novel technique adapts working models and technologies for new food traceability cases. Our sensor end node is reusable and reprogrammable for different real-time traceability of food products.

Key words*: Internet of Food, LoRaWAN, Food Traceability, Computer systems.*

1. Introduction

Food quality and safety control is an important factor in avoiding food poisoning. In recent years, particular attention has been paid to the traceability of inputs in the food industry. All food processing companies are required to build and maintain system for hazard analysis and control of critical points (HACCP). Food tracking is turning more into a growing concern for consumers and scientists around the world. Food tracking is currently carried out mainly at the administrative level, using the means of documentary tracking of raw materials and end products. Tracing became a legal instrument in 2005 in Europe, applicable to all marketable foodstuffs in order to guarantee their food safety Article 18 of EU Regulation 178/2002 [1]. In these circumstances, it became imperative to implement tracing systems to minimize the production and spread of hazardous or poor quality food. The evolution of computer technology requires a shift to real-time traceability. For building of such modern systems the experience gained from the evolution of the internet of things (IoT) can be used. Based on the use of network connectivity of objects, a new trend is being developed, called internet of food (IoF). Building an infrastructure for internet of food about active mobile traceability is in its infancy, and many scientists are offering different conversion models. The purpose of all proposed solutions is to collect objective machine information about the basic technological parameters for processing and food sales. The range of software and technology tools for realizing the active mobile traceability of food is diverse. Regardless of the solutions offered, end nodes are a key element in any active food quality monitoring system. The sensor node is in direct access to raw materials and end products and determines what technological parameters will be monitored and archived. The end mobile node requires web monitoring.

Present paper provides an exemplary end node implementation solution that allows control of basic food storage parameters such as temperature, humidity, colour, and a mobile food monitoring application in network environment. For network connectivity an advanced wireless technology with a large enterprise scale is used. This paper also provides an example solution for active tracking, taking into account current trends for network connectivity between objects based on modern computer systems and technologies.

2. Materials and Methods

Along with globalization, traditional labelling and paper based tracking techniques are not adequate and the progress in implementing electronic methods is desirable for an effective tracking system. Radio frequency identification (RFID) as an electronic labelling technology is now required. RFID technology uses different frequencies and identifiers. RFIDs have an antenna for transmitting and receiving of radio signals. Passive RFID chips do not have their own power supply while active ones do. RFID identifiers can be attached to objects such as labels, tags, cards, capsules, disks, as passive identifiers can even be injected into objects. Most RFID systems operate in the low frequency range (LF - typically 125 kHz) according to ISO/IEC 18000 and the high frequency range (HF - usually 13.56 MHz) according to ISO/IEC 15693. In fact, LF RFID type systems have already found a number of applications when the label is applied to organic tissues such as animal identification, according to ISO 11784, where the tag is applied directly to the animal's ears, neck or feet, or even injected or ingested. Another case of electronic labelling is the identification of metal containers, structures or machinery where food is handled, for example in bulk (buckets, boxes, etc.), metal shelves and more. LF RFID systems are used for the modern labelling of dairy products, cheeses, animals, apples [2]. A major disadvantage of the LF RFID systems offered is that they are passive and cannot transmit real-time food tracking information. The most important question in the food industry is how to measure the temperature in possible food products without much investment. Even if new HF RFID semi-passive systems with built-in temperature sensors are used, they operate at 13.56 MHz, with low transmit power and have a read range not exceeding three centimetres. The extraction of such technological information is not even active in this case and occurs after a certain life cycle of the food. Is there a solution to implement a system for transmitting technological information in real time? Yes, this is possible using new communication technologies [3] and building a sensor network transmitting information of food traceability on Internet. A comparison of widespread wireless technologies is given in Table 1.

LoRa technology belongs to the group of energy-efficient global networks type LPWAN, bluetooth belongs to the group of personal wireless networks (WPAN) with a group of IEEE 802.15 standards, and Wi-Fi - to the local wireless networks (WLAN) with standards of IEEE 802.11 [4]. Among the technologies presented, the most relevant to implementation of an active food traceability system is the LoRa standard, defined by the LoRa Alliance, [5], since it supports a large number of devices that have low power consumption, are suitable for battery power, possess the largest range of technologies available, have low power consumption in active mode and the ability to build expandable star topology networks. In addition, LoRa provides a secure connection using a 128-bit encryption key [6]. The specifications of LoRaWAN™ standard are different depending

Table 1. Main features of wireless networks

Features	LoRa	Bluetooth	Wi-Fi
Operating frequency	868/915 MHz	2.4 GHz	2.4 GHz
Network nodes [max]	65 536	7	32
Wake up time	30 ms	10 s	3 s
Data Speed [max]	22 Kbps	24 Mbps	600 Mbps
Topology	star	tree	tree
Extension method	Automatic	None	Automatic
Range	5 - 15 km	0.1 km	0.250 km
Battery power time	Years	Days	Hours
Standby Current, A	3×10^{-6}	200×10^{-6}	20×10^{-3}
Low power mode	Supporting	No	No

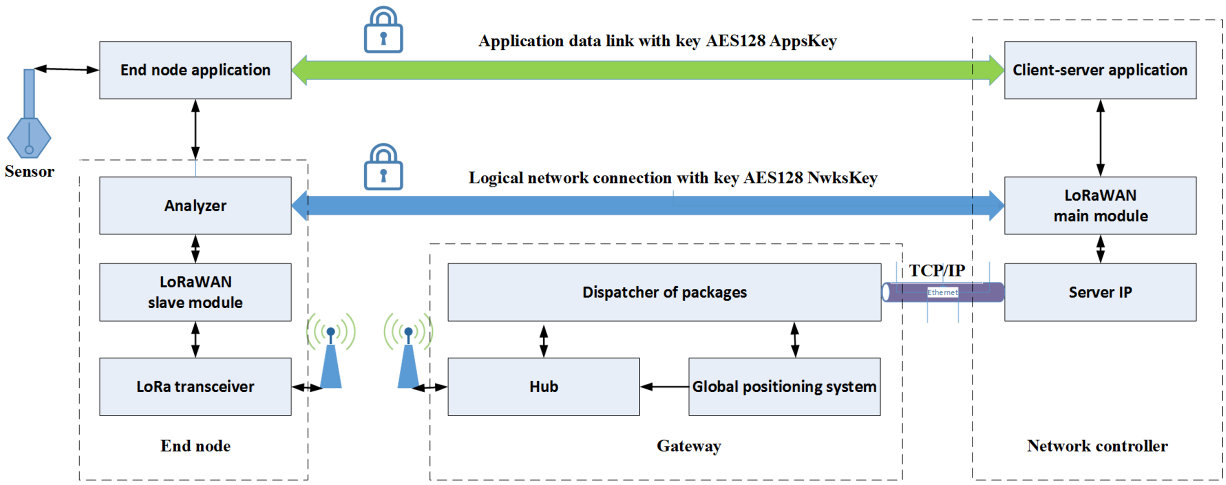

Figure 1. Flow diagram of data protection

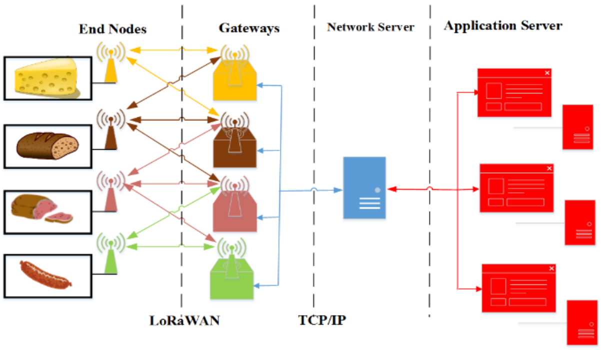

Figure 2. Functional diagram of the infrastructure for active food traceability system

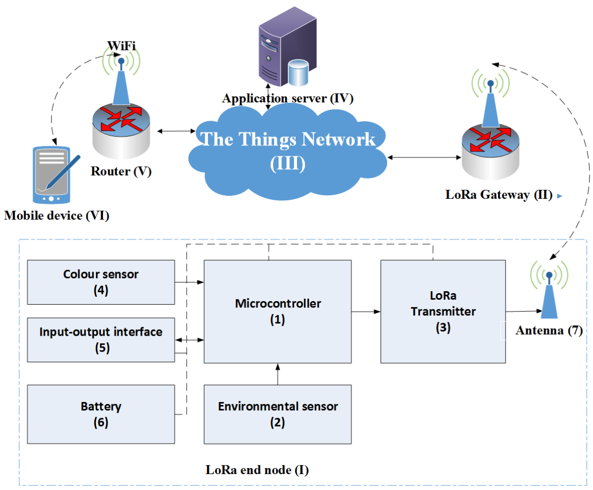

Figure 3. Block diagram of a food traceability system

on the communication spectrum allowed. For Europe the frequency range is 867 MHz to 869 MHz, divided into ten channels (eight for 5.5 kbps, one for 11 kbps and one for 50 kbps) and a maximum output power of +14 dBm. End nodes of this standard allow two-way communication up to 5 km in urban area. LoRaWAN™ has two security levels based on 802.15.4 Security. Network security guarantees the authenticity of the node in the network, while the application security layer ensures that the network operator does not have access to the end-user application data, as shown in Figure 1.

At first glance, the lower speed for transmitting LoRa data over the other technologies presented is not a disadvantage, since sensor networks do not transmit large amounts of data and multimedia content, but technological data (usually temperature, humidity, pressure) which do not require high speed for transmission. One possible variant of a functional structure for building separate branches of network infrastructure for active food traceability based on existing Internet of Things systems is shown in Figure 2.

3. Results and Discussion

On the basis of the proposed network infrastructure for active food traceability by integrating LoRa embedded microprocessor modules, a model of a computer system for implementing food traceability, identification and monitoring is shown in Figure 3.

Modern computer modules have been selected for the hardware implementation. The main modules of our food traceability system are: I - LoRa end node, II - Lora gateway, III - The things network, IV - Application server, V - Router and VI - Mobile device. Our end sensor node consists of a microcontroller (1), an environmental sensor (2), a LoRa transceiver, a colour sensor, an I/O interface for further expansion (5) and a battery (6).

In the attached structure the main component for data collection is the end node. We offer our own version of the end sensor node. On the basis of the proposed structural diagram, the schematic-technical part of the computer system of the final node was developed, based on the general principles for implementation of embedded microprocessor systems and choice of

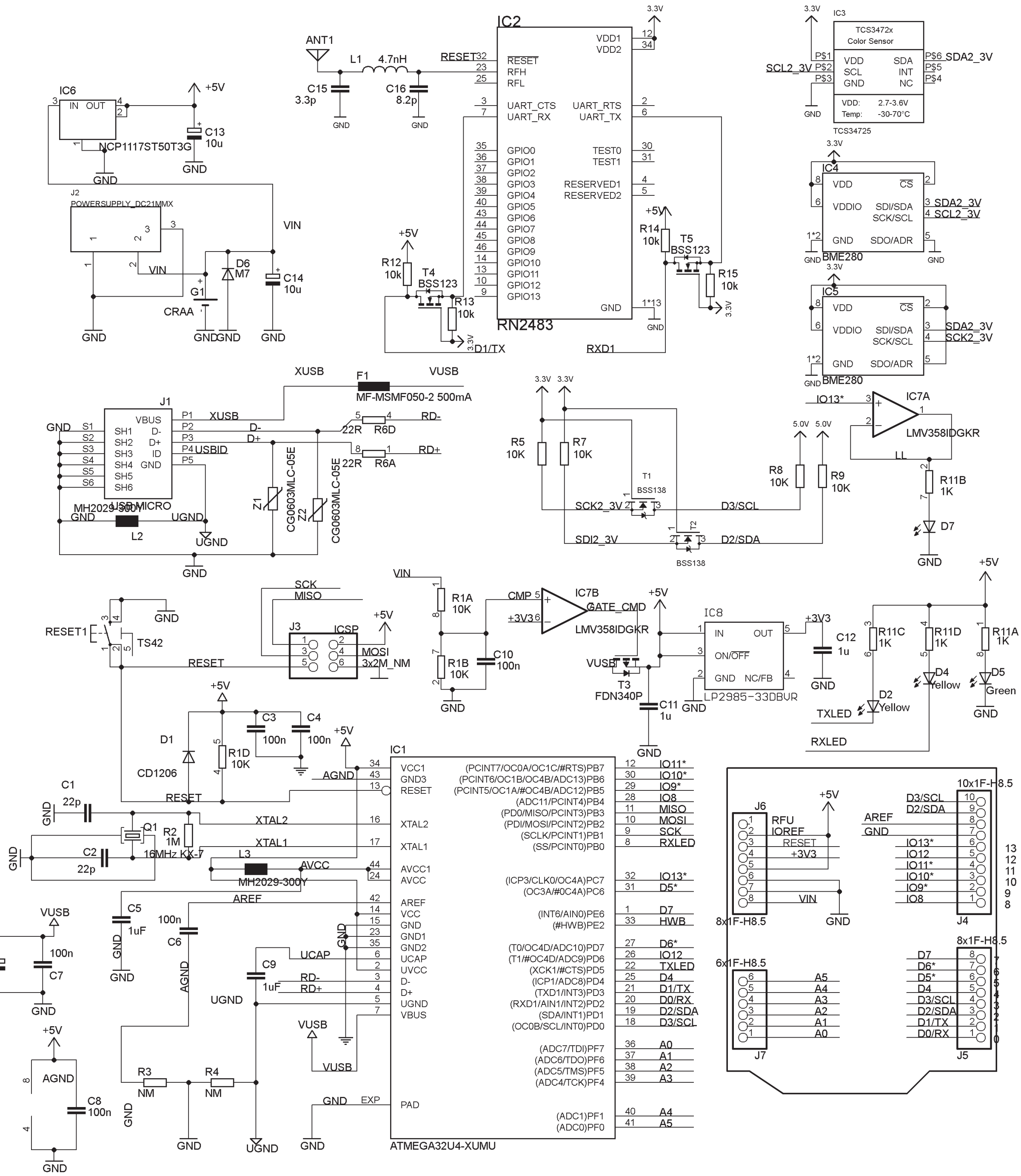

Figure 4. Schematic diagram of the end node

modern architectural solutions. On Figure 4 is shown the schematic diagram of the realized end-to-end food traceability node.

The synthesis of the microprocessor system is based on a built-in microcontroller in a single chip ATmega32u4 (IC1). The ATmega32u4 is a high-speed ultra-low consuming 8-bit RISC based microcontroller with 32KB flash memory, 1 KB electrically erasable programmable read-only memory (EEPROM), 2.5 KB static random-access memory (SRAM), 26 programmable I/O Lines, one 8-bit Timer/Counter, two 16-bit timer/counter, one 10-bit high-speed timer/counter timer modules, internal and external interrupt sources of microprocessor, USB 2.0 full-speed device module, one sequentially programmable universal synchronous and asynchronous transceivers (USART), 12-channels 10-bit analogue-to-digital converter (ADC), one inter-integrated circuit (I^2C) interface, one serial peripheral interface (SPI), and programmable watchdog timer. The microcontroller operates with a voltage between 2.7 and 5.5 volts [7]. ATmega32u4 uses free software from the manufacturer and the free development environment as AVR studio. The proposed end node is programmed via USB port with Arduino IDE. The RESET button is standard on this type of microcontroller and produces a signal for the initial establishment of the microprocessor system. The C1, C2, and Q1 elements are standard for the implementation of an external frequency group of the microprocessor clock generator. The power supply to the microprocessor system is realized by means by battery power 9V. The IC8 controller provides 3.3V DC for the transceiver and sensors. The Lora transceiver is based on Microchip RN2483 integrated circuit (IC2). The RN2483 has an acceptance sensitivity of about -146 dBm. Power consumption of the transceiver in sleep mode is 2uA and standby 2.8mA. The transmit power output is adjustable up to +14 dBm high. The RN2483 has a built-in 256 byte RAM for data buffer available in LoRa mode [8]. The communication between microcontroller and Lora transmitter is via built serial interface. Level synchronization is made by T4 and T5. The LoRa transmitter uses a common antenna. The antenna is interchangeable with the SMA/UFL connector for the use of different antenna systems depending on the gateway coverage. The TCS34725 (IC3) is the digital colour sensor. The TCS34725 device provides a digital return of red, green, blue (RGB), and clear light sensing values to simultaneously 16-bit digital values. Communication of the TCS3472 data is accomplished over two-wire I^2C serial bus 0x39 address [9].The IC4 temperature/humidity sensor is an integrated digital type BME280 with I^2C address 1110110 (0 x 76). The IC5 temperature/humidity sensor is an integrated digital type BME280 with I^2C address 1110111 (0 x 77). The BME280 measures temperatures in the range of -40 to +85 ^{0}C with an accuracy of ± 0.5 ^{0}C and relative humidity in the range of 0 to 100% with an accuracy of ± 3% [10]. The resolution of the temperature measurement is 20 bit ADC output and resolution of the humidity measurement is fixed at 16 bit ADC output. The main purpose of our module for food traceability is active monitoring of meat products. Sensor module for food traceability is of the integral type for given technological parameters. The input interface of the end nodes supports digital and analogue sensor inputs, so that the sensors can have different interface signals for adaption of others food products. Sensor selection can be for:

- Temperature LM75A, LM35D, TMP36, DS18B20 and others.
- Colour TCS3200, TCS34725, TCS3414 and others.
- Pressure MS5540, MPX5500 and others.
- Humidity Si7021, HS1101 and others.
- pH InLab Reference Plus, InLab Solids Pro-ISM and others.
- Gases MQ-2, MQ-3, MQ-4, MQ-5, MQ-6, MQ-7, MQ-8, MQ-9, MQ-135 and others.

Programming of the end nodes is done independently depending on the specific environmental sensor selected. In doing so, the end nodes allow bootloader programming modes and an external programmer. Open source software is used to implement the sensor programming utility.

The algorithmic diagram of the designed end node is shown in Figure 5.

The main way for communicating with a LoRaWAN end node via the things network (TTN) passes through TTN Console.

We have developed an exemplary web application and named it "Live food web application" that acts as a dashboard. A screenshot of the real-time panel of our application in working mode is shown in Figure 6. It is intended for providing the ability to monitor different

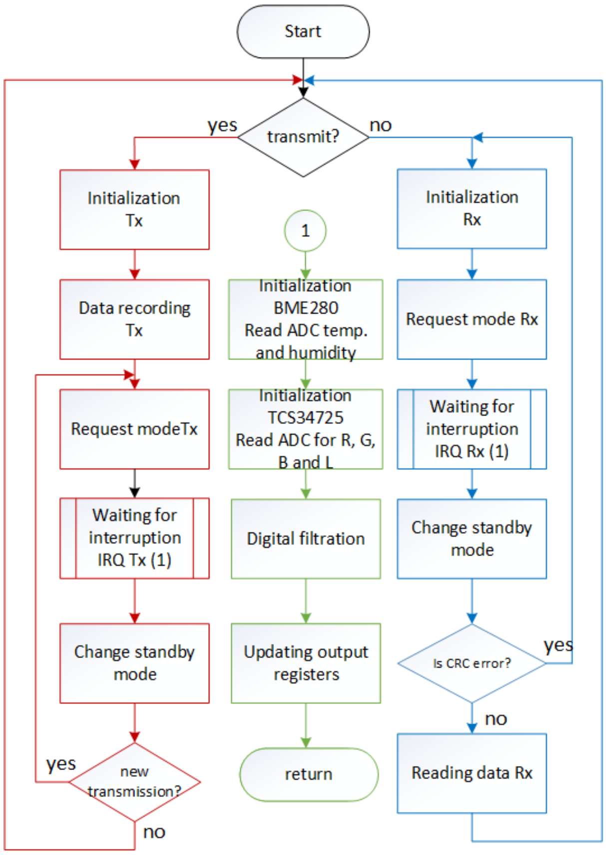

Figure 5. Algorithmic diagram of the sensor node

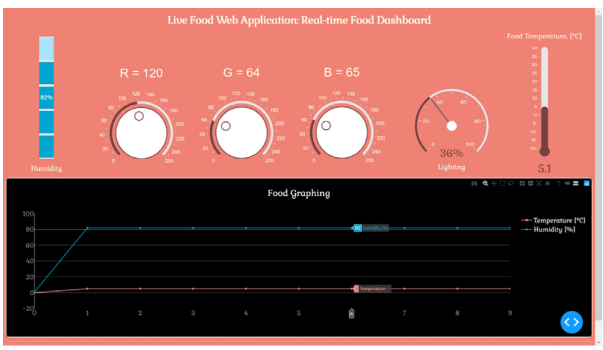

Figure 6. A screenshot of our web application rendered in a web browser

technological conditions in real time, for example conditions in meat products during storage.

Our dashboard is updating on a predefined interval of time. It listens for call-back events on the predefined interval. The data, visualizing on the dashboard, are being fetched by the sensors of our end device put on a suitable place inside the storage area. The app pulls live data from TTN via MQTT (message queuing telemetry transport) protocol through the provided Python SDK (software development kit) and parameters like temperature, colour of meat and humidity of storage can be updated on panel's display every set updating time. Except the possibility of a real-time monitoring of sensor data, the web application is capable of storing the data into CSV (comma separated values) spreadsheets that can be uploaded and previewed any time the user needs some information for past recorded data. This function acts like a database and on the panel is available under the name "Load stored CSV data" which has the functionality of a button opening a file explorer window for uploading and rendering the created spreadsheet file. Pre-set click-and-run ready integrations of TTN could provide such functionalities but the occasions where components of different nature are combined in a common panel are rare and may cost us a sum when we choose such an option. Figure 7 presents a flowchart diagram tracing the course of action of our developed web application.

We build our web application with the kind assistance of the Python's Dash framework, using TTN provided Python Application SDK which allows transceiving messages to and from IoT devices [11].

4. Conclusions

- The construction of the Infrastructure for food traceability system requires special attention to the selection and design of the sensor end node. These devices work with different objects with different characteristics at different food technological parameters.

- Presented structure for the implementation of a system based on the microcontroller ATmega32u4 and the RN2483 transmitter allows basic food storage parameters to be monitoring.

- Proposed system is hardware open and allows to expand with different types of sensors.

- Proposed structure adapts working models and technologies, which is why it will find application in new food traceability systems.

- Proposed end node is reusable and as low cost as possible for mass battery powered use.

- Main application of developed system is to be used for monitoring and data acquisition with food traceability sensors.

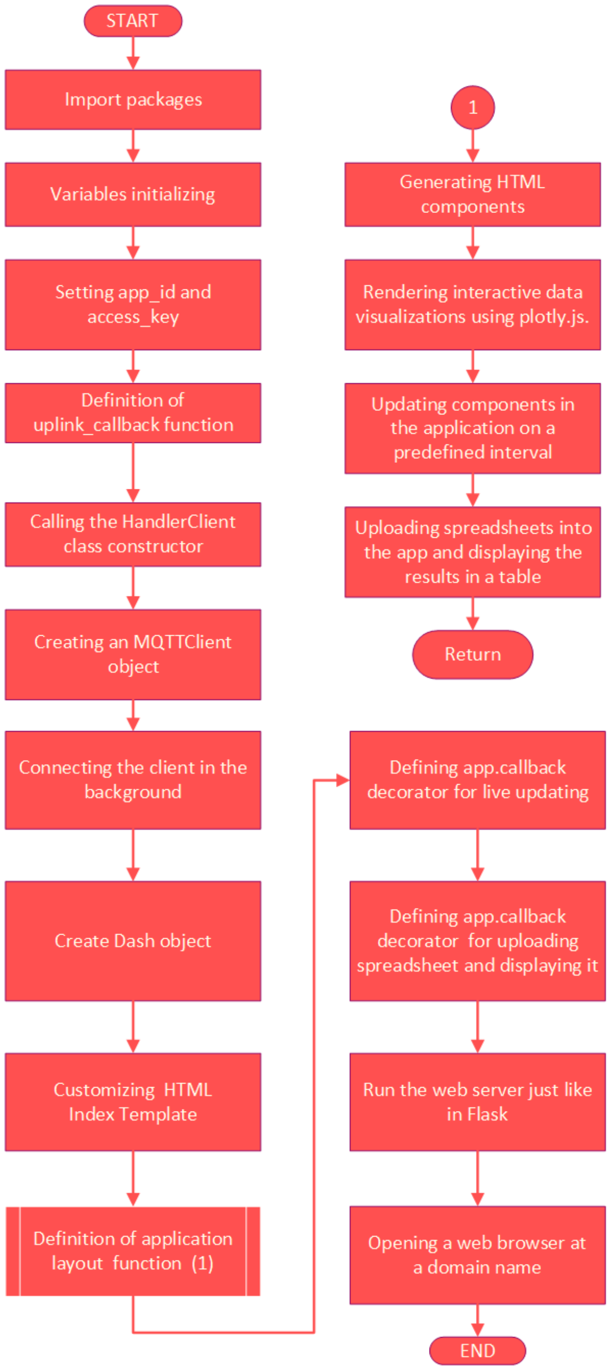

Figure 7. Flowchart diagram of web application for a food traceability system

- Future design of the infrastructure for food traceability system also needs to take into account the development of emerging wireless technologies, as well as standards more closely focused on cloud technologies for data collection and processing. Such our dashboard can live not only within the boundaries of local area networks but also on public communities in Internet accessible from every Internet connected node of the world for food monitoring and traceability. Such advantages of custom dash web applications give the sense of the Internet of things for food traceability.

The main advantages of dash-based web applications, together with LoRaWAN, over ready pre-set dashboards, are the accessibility and flexibility of its source code for novel food traceability system.

5. References

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