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CONTENT

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INTEGRATED RF-WIFI SMART SENSOR NETWORK

GOCE STEFANOV, MAJA KUKUSEVA PANEVA, SARA STEFANOVA

Abstract. In this paper, an integrated smart sensor network has been designed and practically realized. The purpose of the integrated RF-WIFI smart sensor network is time collection, visualization, and analysis of signals from industrial equipment in standalone plants as well as integration of this data into Intra and Internet network. The network consists of two microcontrollers systems. The first microcontroller collects data from sensors in standalone industrial plants and sends them via RF connection to a master station. The second microcontroller in the master station receives data from the RF network, processes, visualizes, and stores the data in a data log file and distributes the data via WIFI connection to the Internet.

Keywords: RF- WIFI, Sensor Network, Data log file

1. Introduction

In real industrial processes there are standalone plants that represent a separate whole. Most often, these plants are far from intra and internet network of the production companies. In such plants, data distribution from process quantities (voltage, current, pressure, flow, temperature, etc.) to the master station is through radio frequency connection (RF)[1], [2], [3].

There are various wireless communication technologies used in building IoT applications and RF (Radio Frequency) is one of them. Usually, such radio communications are two-way (bidirectional) [4]. In Figure 1 a block diagram of one RF sensors network is shown.

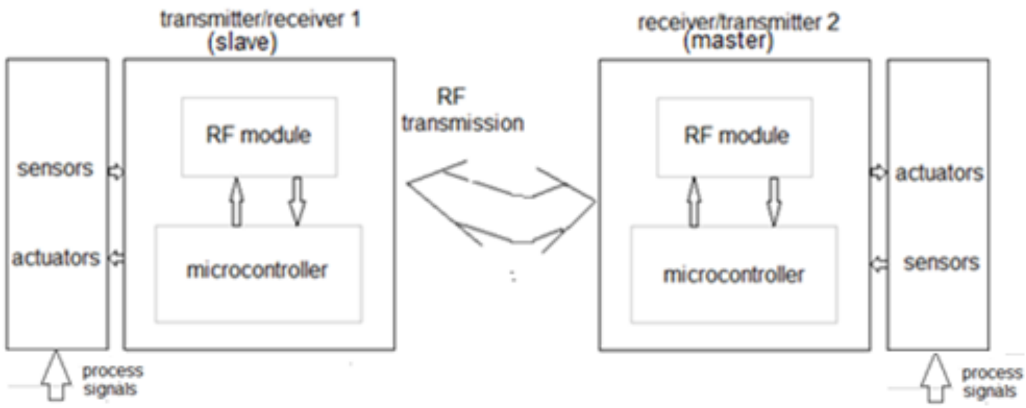


Figure.1. *Block diagram of bidirectional RF sensors network*

Transmitter/receiver 1 (slave station) and receiver/transmitter 2 (master station) on both sides consist of sensors network and actuators, RF module and microcontroller. The solution shown in Figure 1 provides the possibility to connect the process quantities of a standalone plant in the intra network of the manufacturing company. In case the data needs to be distributed on the Internet, the Master station is upgraded as shown in the block diagram in Figure 2.

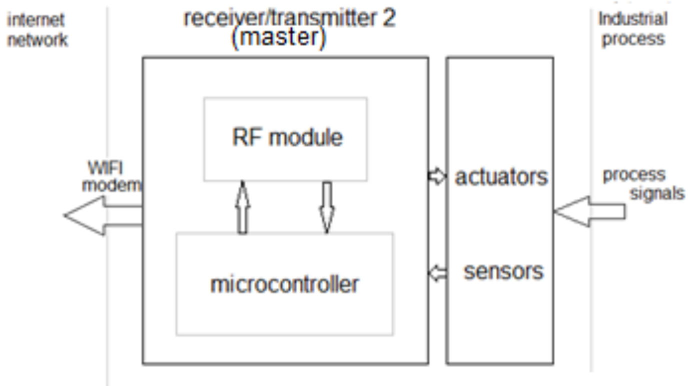


Figure 2. *Block diagram of one RF-WIFI Master station build in industrial plants*

From Figure 1 and 2 it can be seen that an integrated smart sensor network is based on microcontrollers, RF modules and WIFI interface. The Slave micro controller collects data about the quantities of the industrial process through the sensor network and with RF communication it sends the collected data to the Master microcontroller that is connected to the Internet network with a WIFI modem [5]. The master microcomputer is connected to a personal computer through a UART port and sends the collected data to the Intra network. This hardware architecture on the one hand provides data adequate to the conditions in the industrial process to be collected and visualized on LCD displays and on a personal computer, and on the other hand the possibility for distribution of data in the Internet network is created.

2.Design of an Integrated RF-WIFI Smart Sensor Network

In industrial plants there are parts that are remote from the intra and internet network. In such standalone plants there is a problem with time collection, visualization, and analysis of signals from sensors that are important for the proper functionality of the industrial equipment. The design of a RF-WIFI Smart Sensor Network in this paper solves this problem and enables integration of signals from standalone plants in the intra and internet network. The design of the integrated RF-WIFI network consists of the design of the Slave RF network and the design of the RF-WIFI Master network.

2.1 Design of a Slave RF Sensor Network

In this part a Slave RF network is designed. This network is based on a RF module NRF24L01 and a microcontroller [5]. The designed Slave RF network has the task to measure the temperature and the humidity at the measuring point and it sends the measured values via RF transmission to the receiving point in the Master station. In Figure1 a block diagram of the designed Slave RF sensor network is shown.

The Slave RF network consists of a temperature sensor with the component DHT11, NRF24L01 module and the microcontroller Atmega 328P on Arduino uno board.

2.1.1 Features of the used hardware

a.) *NRF24L01 module*

NRF24L01 is a single-chip radio transceiver module that operates on 2.4 - 2.5 GHz (ISM band) [5]. This transceiver module consists of a fully integrated frequency synthesizer, a power amplifier, a crystal oscillator, a demodulator, a modulator, and an Enhanced ShockBurs protocol engine. Output power, frequency channels, and protocol setup are easily programmable through an SPI interface. Built-in Power Down and Standby modes make power saving easily realizable. In Figure 3 an electronic board on NRF24L01 module and its pinout are shown.

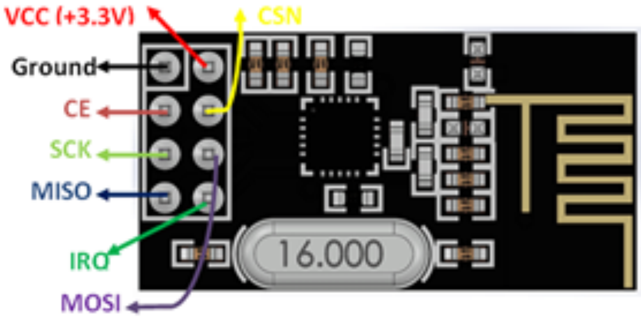


Figure 3. *Electronic board of NRF24L01 module and its pinout*

In Table 1 the pinout configuration on an NRF24L01 module is given.

Table 1: Pinout configuration on an NRF24L01 module

Pin Number	Pin Name	Abbreviation	Function
1	Ground	Ground	Connected to the Ground of the system
2	Vcc	Power	Powers the module using 3.3V
3	CE	Chip Enable	Used to enable SPI communication
4	CSN	Ship Select Not	This pin has to be kept high always; else it will disable the SPI
5	SCK	Serial Clock	Provides clock pulse for SPI communication
6	MOSI	Master Out Slave In	Connected to MOSI pin of MCU, for the module to receive data from the MCU
7	MISO	Master In Slave Out	Connected to MISO pin of MCU, for the module to send data from the MCU
8	IRQ	Interrupt	It is an active low pin and is used only if interruption is required

NRF24L01 Features:

- 2.4GHz RF transceiver Module
- Operating Voltage: 3.3V
- Nominal current: 50mA
- Range: 50 – 100 m
- Operating current: 250mA (maximum)
- Communication Protocol: SPI
- Baud Rate: 250 kbps - 2 Mbps.
- Channel Range: 125
- Maximum Pipelines/node: 6
- Low-cost wireless solution

The NRF24L01 is a wireless transceiver module, meaning that each module can both send as well as receive data. The operating frequency is 2.4 GHz, which falls under the ISM band and hence it is legal to use in almost all countries for engineering applications. When the modules operate efficiently, it can cover a distance of 100 meters (200 feet) which makes it a great choice for all wireless remotely controlled projects.

The module operates at 3.3V hence it can be easily used with 3.2V systems or 5V systems. Each module has an address range of 125 and each module can communicate with 6 other modules hence it is possible to have multiple wireless units communicating with each other in a particular area. So, mesh networks or other types of networks are possible using this module. Therefore, this module is an ideal choice for practical applications.

The NRF24L01module works by means of SPI communications. These modules can either be used with a 3.3V microcontroller or a 5V microcontroller with an SPI port. The complete details of usage of this module through SPI are given in the data sheet below. The circuit diagram in Figure 4 shows the module should be interfaced with the microcontroller. In Figure 4 the usage of 3.3V microcontroller is shown, but it is applied in the same way for a 5V MCU. The SPI Pins (MISO<MOSI and SCK) are connected to the SPI pins of the microcontroller and the signal pins (CE and CSN) are connected to the GPIO pins of the MCU. There are ready made available libraries, like R24 Library, for interfacing this module with Arduino.

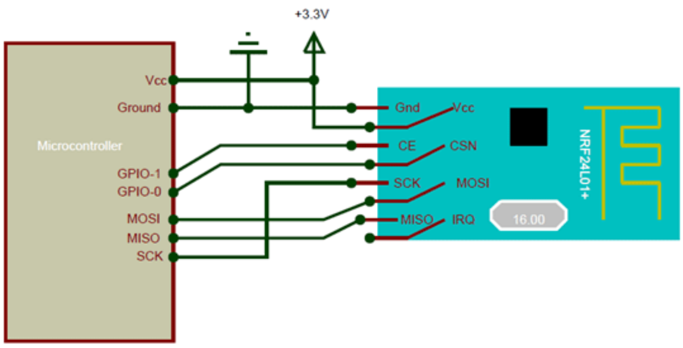
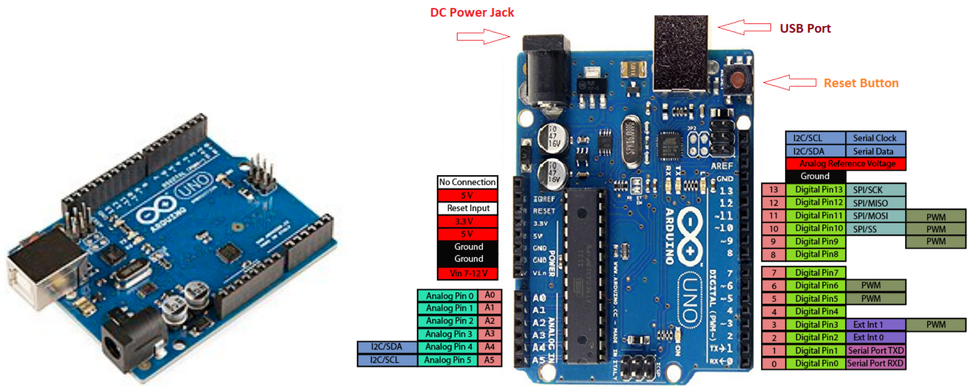


Figure4. *NRF24L01 module interfaced with a microcontroller*

With the help of these libraries, NRF24L01can be easily interfaced with Arduino with a few lines of code. If using some other microcontroller, the datasheet has to be read in order to understand how to establish SPI communication. The NRF24L01 module is a bit tricky to use, especially since there are many cloned versions on the market. In case of troubleshooting, 10µF and 0.1µF capacitors should be added in parallel to source Vcc and Ground pins. Also, the 3.3V supply should be clean and not have any noise coupled in it.

b.) Microcontroller Atmega 328P

The Arduino Uno is an open-source microcontroller board based on the MicrochipATmega328P microcontroller and developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 digital I/O pins (six capable of PWM output), 6 analog I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment), via a type B USB cable. It can be powered by the USB cable or by an external 9-volt battery, though it accepts voltages between 7 and 20 volts. The word "uno" means "one" in Italian and was chosen to mark the initial release of Arduino Software. The Uno board is the first in a series of USB-based Arduino boards; this and version 1.0 of the Arduino IDE were the reference versions of Arduino, which have now evolved into newer releases. The ATmega328P on the board comes preprogrammed with a bootloader that allows uploading a new code to it without the use of an external hardware programmer [6]. In Figure 5a an electronic board of Arduino Uno with build Atmega 328P microcontroller is shown, and in Figure 5b its pinouts are shown.



a.) b.)

Figure 5.*a.) Arduino Uno and b.) pinout*

c.) DHT11 temperature and humidity sensor

The DHT11 are commonly used temperature and humidity sensors. The sensor comes with a dedicated NTC to measure temperature and an 8-bit microcontroller to output the values of temperature and humidity as serial data. The connection diagram for this sensor is shown in Figure 6.

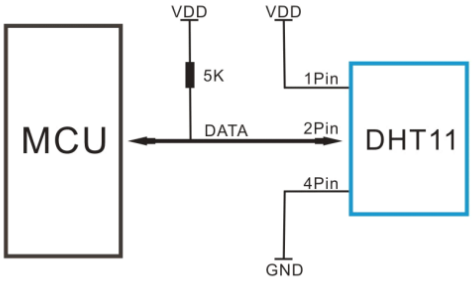


Figure 6. *Connection diagram for DHT11 sensor*

The sensor is also factory calibrated and hence can easily interface with other microcontrollers. The sensor can measure temperatures in the range from 0°C to 50°C and humidity from 20% to 90% with an accuracy of ±1°C and ±1%. The DHT11sensor is factory calibrated and outputs serial data and hence it is highly easy to set it up. From Figure 7 it can be seen that the data pin is connected to an I/O pin of the MCU and a 5K pull-up resistor is used. This data pin outputs both temperature and humidity values as serial data. For the interface of DHT11 with Arduino there are ready-made libraries for a quick start. If it is needed to interface it with some other MCU, then the datasheet given below is handy. The output given by the data pin is sent to the order of 8bit humidity integer data + 8bit humidity decimal data +8-bit temperature integer data + 8-bit fractional temperature data and +8 bit parity bit. The duration of each host signal is explained in the DHT11 datasheet, with neat steps and illustrative timing diagrams. This sensor can be used for temperature and humidity measurement, local weather station, automatic climate control and environment monitoring. In Figure 7 a real size DHT11 sensor with its pinout is shown.

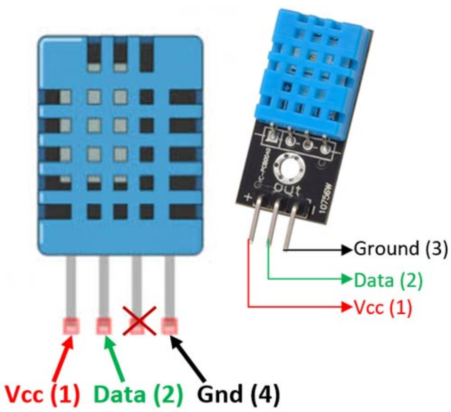


Figure 7. *DHT11 sensor and pinout*

DHT11 Specifications:

- Operating Voltage: 3.5V to 5.5V
- Operating current: 0.3mA (measuring) 60uA (standby)
- Output: Serial data
- Temperature Range: 0°C to 50°C
- Humidity Range: 20% to 90%

- Resolution: Temperature and Humidity both are 16-bit
- Accuracy: ±1°C and ±1%

The **DHT11 sensor** can either be purchased as a sensor or as a module. Either way, the performance of the sensor is the same. The sensor comes as a 4-pin package out of which only three pins are used whereas the module comes with three pins as shown above. The only difference between the sensor and the module is that the module will have a filtering capacitor and a pull-up resistor inbuilt, and for the sensor they are externally used if required.

2.2 Design of a Master RF-WIFI Smart Network

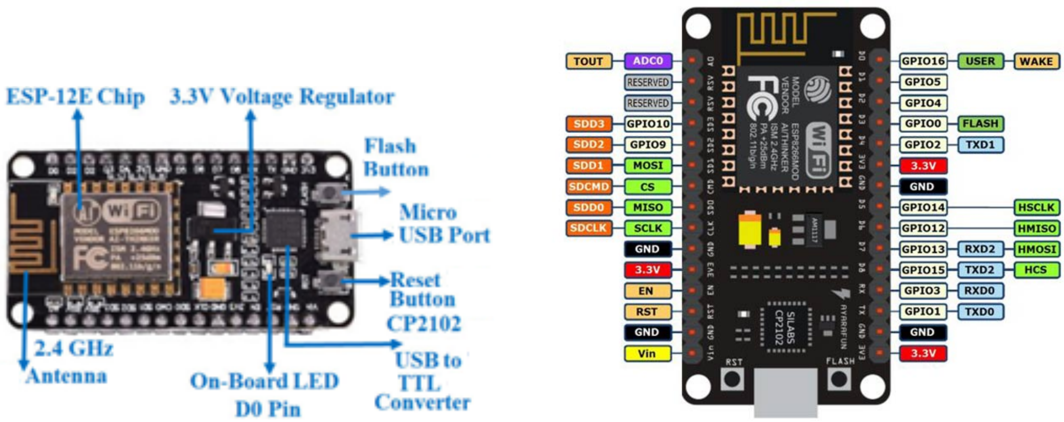
The Master smart network receives the data from Slave with RF communication and the values are displayed on an LCD screen and stored on a PC in a data log file compatible with Microsoft Excel. The Master network also has a WIFI modem for connecting the Internet as shown in Figure 2.

The main part of the smart Master network is the microcomputer. In the solution represented in this paper the NodeMCU ESP8266 [7] is selected that supports the WIFI connection.

2.2.1Features of the used hardware

Microcontroller NodeMCU ESP8266

The NodeMCU ESP8266 development board comes with the ESP-12E module containing an ESP8266 chip having a Tensilica Xtensa 32-bit LX106 RISC microprocessor. This microprocessor supports RTOS and operates at 80MHz to 160 MHz adjustable clock frequency. NodeMCU has 128 KB RAM and 4MB of Flash memory to store data and programs. Its high processing power with in-built Wi-Fi / Bluetooth and Deep Sleep Operating features makes it ideal for IoT projects. NodeMCU can be powered using Micro USB jack and VIN pin (External Supply Pin). It supports UART, SPI, and I2C interface. In Figure 8 a NodeMCU ESP8266 and its pinout are shown.



a.) b.)

Figure 8.a.) *NodeMCU ESP8266 and b.) pinout*

NodeMCU is an open source-based firmware and development board specially targeted for IoT based applications. It includes firmware that runs on the ESP8266 WIFI SoC from Espress Systems, and hardware which is based on ESP-12 module.

NodeMCU ESP8266 specifications & features

- Microcontroller: Tensilica 32-bit RISC CPU Xtensa LX106
- Operating Voltage: 3.3V
- Input Voltage: 7-12V
- Digital I/O Pins (DIO): 16
- Analog Input Pins (ADC): 1
- UARTs: 1
- SPIs: 1
- I2Cs: 1
- Flash Memory: 4 MB
- SRAM: 64 KB
- Clock Speed: 80 MHz
- USB-TTL based on CP2102 is included onboard, Enabling Plug n Play
- PCB Antenna
- Small Sized module to fit smartly inside your IoT projects

The NodeMCU ESP8266 board can be easily programmed with Arduino IDE since it is easy to use. The pinout for this microcomputer is given in [7].

3. Experimental results

In this section, specifically given electronic solutions for Slave and Master Network and the results of their experimental work are represented.

a.) Slave *RF Network*

In Figure 9 the connection of the components of Slave RF side is shown. The Slave side consists of an Arduino UNO, NRF24L01 module and DHT11 sensor. Interfacing of the Arduino UNO with NRF24L01 and DHT11 is shown below. Arduino continuously gets data from a DHT11 sensor and sends it to the NRF24L01 Transmitter. Then the RF transmitter transmits the data into the environment.

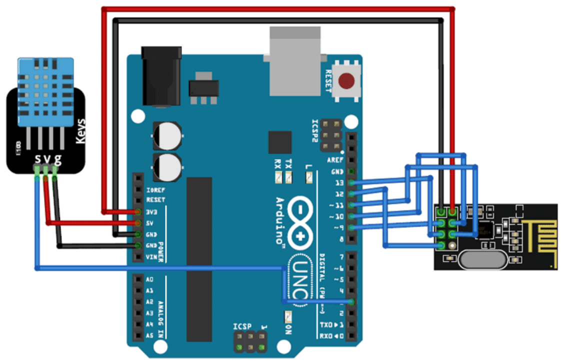
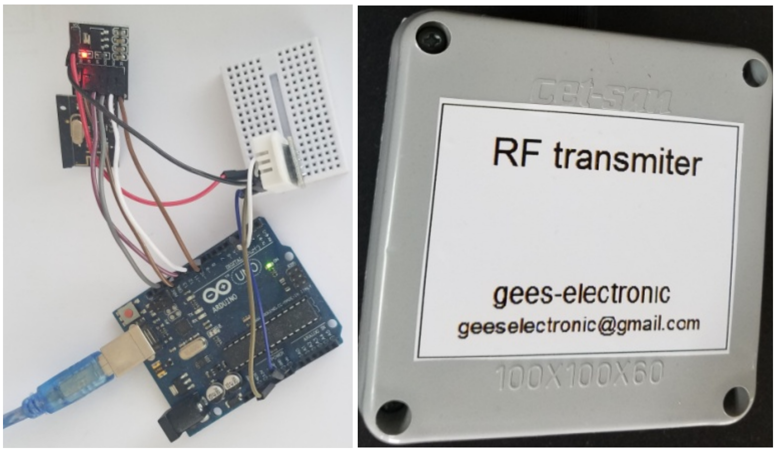


Figure 9. *The connection of the components of Slave RF side*

Connected on NRF24l01, Arduino Uno and DHT11 are given in [7]. In Figure 10 the experimental realized prototype of Slave RF network is shown, and Figure 10b shows the finished Slave RF device.



a.) b.)

Figure 10. Slave *RF device: a.) experimentally realized prototype of Slave RF network and b.) finished Slave RF device*

b.) Master RF-WIFI Smart Network

In Figure 11 the connection of the components of Master RF-WIFI side is shown. The Master side consists of an ESP 8266-12E, NRF24L01 module and LCD display.

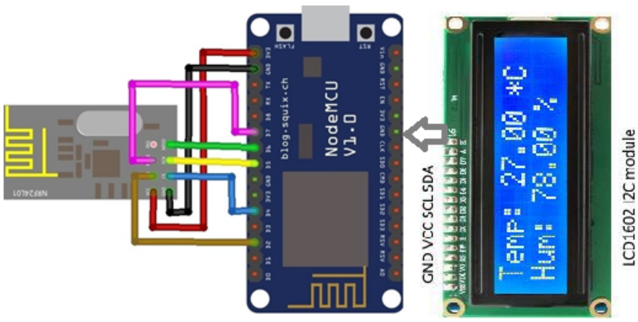


Figure 11. *The connection of the components of Master RF-WIFI side*

Connection on NRF24L01 with NodeMCU ESP8266 Board is:
MISO connects to **pin D6** of the NodeMCU
MOSI connects to **pin D7** of the NodeMCU
SCK connects to **pin D5** of the NodeMCU
CE connects to **pin D4** of the NodeMCU
CSN connects to **pin D2** of the NodeMCU
GND and **VCC** of the NRF24L01 are connected to **GND** and **3.3V** of the NodeMCU
In Figure 12 an experimental prototype of Master RF-WIFI network is shown, and in Table 2 the data log file in Microsoft Excel is shown.

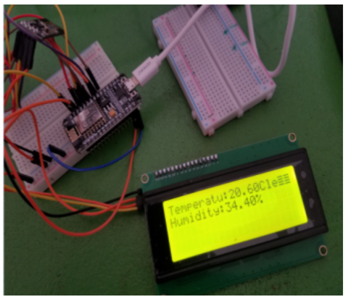


Figure 12. *Experimental results: Prototype of the Master RF-WIFI network*

Table 2: Experimental results in excel data log file

Date	Time	Temperature©	Humidity(%)
6/11/2021	11:41:32	26.5	56.9
6/11/2021	11:42:27	26.5	56.8
6/11/2021	11:42:47	26.7	56.6
6/11/2021	11:42:52	26.7	56.6
6/11/2021	11:42:58	26.7	56.6
6/11/2021	11:43:03	26.7	57.1
6/11/2021	11:43:08	26.7	57.5
6/11/2021	11:43:13	26.7	57.1
6/11/2021	11:43:18	26.8	56.5
6/11/2021	11:43:23	26.8	56.3
6/11/2021	11:43:28	26.8	56.1
6/11/2021	11:43:33	26.8	56.2
6/11/2021	11:43:38	26.8	56
6/11/2021	11:43:43	26.8	56.1
6/11/2021	11:43:48	26.8	56.2
6/11/2021	11:43:53	26.8	56.2
6/11/2021	11:43:58	26.8	56
6/11/2021	11:44:03	26.8	55.9
6/11/2021	11:44:08	26.9	55.8
6/11/2021	11:44:13	26.8	55.7
6/11/2021	11:44:18	26.8	55.7

Simple Data | Simple Data with Plots | Interactive Bar

For remote transmission and display of current values of the measured data via a WIFI network SCADA is built based on APP Store platform. Figure 13 shows the screen of an Android mobile device on which the current values of the measured data are shown.

Figure 13. *Screen of an Android mobile device*

The designed RF-WIFI smart network provides an opportunity to visualize data on the industrial equipment of LCD display, excel data log file and in internet network on a remote Android mobile. The accuracy and reliability of the data is confirmed by their comparison in the three measuring points LCD display, excel data log file and remote Android mobile.

4. Conclusion

In this paper, along with the theoretical analysis an integrated RF-WIFI smart sensor network is designed and practically realized. This Sensor network enables time collection, visualization, and analysis of the data from industrial equipment in standalone plants and integration of these data into the intra and Internet network. Also, in the deployed Sensor network, the data from a standalone industrial plant are transferred with RF transmission to Masters Station, visualized on the LCD screen, stored in a data log file and distributed in the Internet network. The designed solution increases the availability of the data relevant to the proper functioning of the industrial equipment and thus increases the security of its operation.

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