The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 28, Pages 554-564

ICBASET 2024: International Conference on Basic Sciences, Engineering and Technology

SCADA System for Process Data Exchange in Master Slave RF and Iot Network

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Abstract: In every aspect of our lives, we can observe how automation plays a facilitating role in the performance of responsibilities of a comprehensive rank. Thanks to the development of electronics, today's process measurement systems enable the measurement values of process quantities to be visualized on display, sent remotely, and stored in a file, compatible with future user processing. In this paper are represented results of the development, design and practical implementation of the SCADA system, which enables data exchange between SCADA screen, MASTER and SLAVE stations. The MASTER station is installed in one industrial plant and the SLAVE is installed in another plant. The SCADA monitoring system is built into the MASTER station. The SLAVE station is connected by RF (radio frequency connection) to the MASTER station. In the MASTER and SLAVE station two microcomputers units, as well as appropriate RF modules, are installed. The microcomputer in the MASTER station is serially connected to the IoT microcomputer, for the transfer of measurement data in the Internet network. The solution provides visualization, data log file, and transfer to the IoT network of process data from the two industrial plants.

Keywords: SCADA, Exchange data, RF Network, IoT network

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. Therefore there is a need to automate and connect these plants in the intranet of the company and more widely in the Internet (IoT) network. Automation, control, management, and monitoring processes are of exceptional importance, especially for industrial use,(Bennett, 1982), (Hor, 2005). Efforts are made to ensure more reliable and simpler work, especially for operators who are directly exposed to the proper functioning of the entire industrial process. This approach to work is made possible by the so-called SCADA (**S**upervisory **C**ontrol and **D**ata **A**cquisition) system (Automation Community, 2023), (Myomron). On the other hand, a modern controlled system of an industrial process is fully rounded if in addition to SCADA, it is also connected to an IoT network. Such a concept enables process data to be transferred to any location, visualized in real-time, and stored on a cloud computer.

Commonly, some standalone industrial processes might represent a separate entity. Since these plants are far from the Intra and Internet network of manufacturing companies, the data distribution of analog and digital signals from sensors and actuators of some process quantities (eg voltage, current, pressure, flow, temperature, LEDs, relay, etc.) .) must be made from these remote entities to the master station via wireless communication, most likely a radio frequency (RF) connection (Stefanov, 2021), (nRF24L01), (Single-chip 2.4 GHz Transceiver

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

NRF24L01). There are various wireless communication technologies used in building IoT applications and RF is one of them. Usually, such radio communications are two-way or bidirectional (Single-chip 2.4 GHz Transceiver NRF24L01). In this paper, a prototype of SCADA system for bidirectional exchange of process data between two remote industrial plants is designed.

Design on SCADA System for Exchange Data in Master Slave RF and Iot Network

In Figure 1, a block diagram of a realized SCADA system for Data Exchange in MASTER SLAVE RF and IoT network is shown.

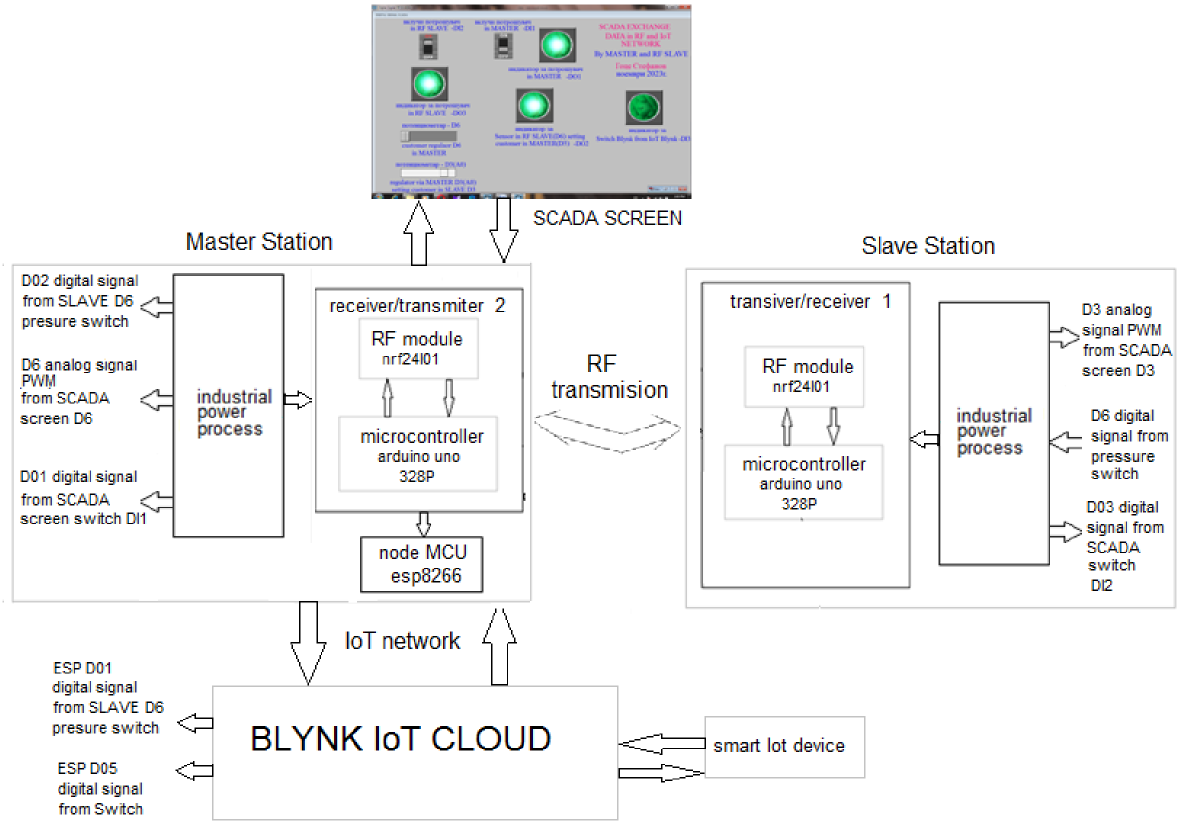


Figure 1. Block diagram of a SCADA system for bidirectional exchange of process data between two remote industrial plants implemented in IoT and RF network

SCADA system enables data exchange between SCADA screen, MASTER and SLAVE stations. The MASTER station is installed in one industrial plant and the SLAVE is installed in another plant. The SCADA monitoring system is built into the MASTER station. The SLAVE station is connected by RF (radio frequency connection) to the MASTER station. In the MASTER and SLAVE stations, two microcomputers units as well as appropriate RF modules are installed. The microcomputer in the MASTER station is serially connected to the IoT microcomputer for the transfer of measurement data in the IoT network.

In the designed SCADA system prototype, switches and LEDs were used as sensors and actuators to verify the correct operation of the solution. The microcomputers in the MASTER and SLAVE stations are 328P on arduino uno board (ATMEGA328P). The microcomputer that allows connecting the system to the IoT network is a nodeMCU esp8266-12E (ESP8266). The design of the prototype system consists of design of the SLAVE and MASTER stations and the design of the SCADA controll system.

Design of the MASTER and SLAVE Station

In real industrial plants there are parts that are remote from intra and internet network. In such standalone plants there is a problem with timely collection, visualization and analysis of signals from sensors that are important for proper functionality of industrial equipment. The designed RF MASTER SLAVE network in this paper solves this problem and enables integration of signals from standalone plants in intra network of the company. In Figure 2 is shown block diagram of RF MASTER SLAVE network (which is part from Figure 1).

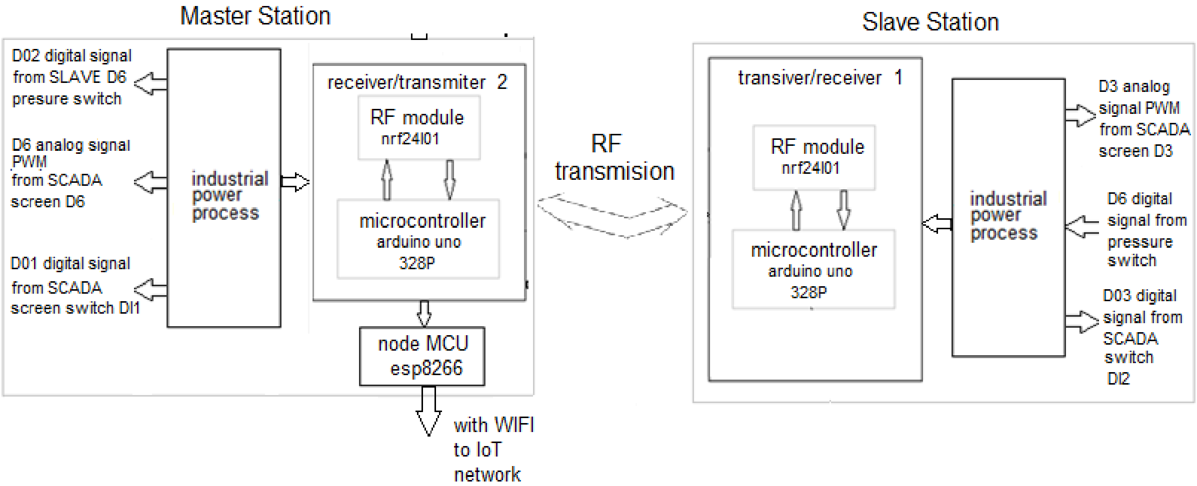


Figure 2. Block diagram of bidirectional RF MASTER SLAVE sensors network

SLAVE and MASTER station on both sides consist of sensors network and actuators, RF module and microcontroller. Such a solution provides the possibility to connect the process quantities of standalone plant in the intra network of the manufacturing company. From Figure 1 and 2 can be seen that this solve is based on microcomputer, RF modules and WIFI interface. The SLAVE microcomputer collects data for the quantities of the industrial process through the sensor network and with RF communication sends collected data to the MASTER microcontroller that is connected to IoT network with a WIFI interface (nodeMCU ESP8266-12e) (Stefanov, 2021). From other hand, the MASTER microcomputer is connected to a personal computer through UART port and sends collected data to SCADA screen and intra company network. This hardware architecture on the one hand provides data, adequate to the conditions in the industrial process to be collected and visualized on SCADA screen on a personal computer and on the other hand the possibility for distribution of data in the IoT network is created. The design of the RF MASTER SLAVE network consists of design of the RF SLAVE station and the design of the RF MASTER station.

The design of the SLAVE station consists of a microcomputer ATmega 328P on an arduino uno board, RF module nrf24l01 (Stefanov, 2021) and appropriate hardware components:
- *switches as sensors*
D6 digital input signal from pressure switch
-*LEDs as actuators*
D3 analog PWM output signal which is active with SCADA screen potentiometer D3
D03 digital output signal which is active with SCADA screen switch DI2

The design of the MASTER station consists of a microcomputer ATmega 328P on an arduino uno board, RF module nrf24l01, nodeMCU ESP8266-12e and SCADA Cx Supervisor design, and appropriate hardware components:
- *switches as sensors*
D6 digital input signal from pressure switch
-*LEDs as actuators*
D02 digital output signal which is active with pressure switch D6 from SLAVE
D6 analog PWM output signal which is active with SCADA screen potentiometer D6
D01 digital output signal which is active with SCADA screen switch DI1

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) (Stefanov, 2021). This transceiver module consists of a fully integrated frequency synthesizer, a power amplifier, a crystal oscillator, a demodulator, a modulator and 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 makes power saving easily realizable. In the Figure 3 is shown electronic board on NRF24L01 module and his pinout.

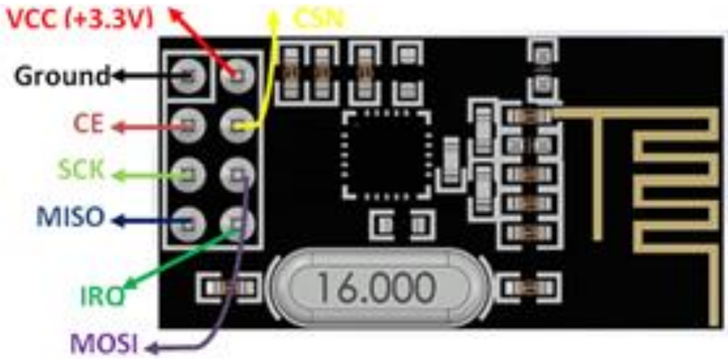


Figure 3. Electronic board of NRF24L01 module and his pinout

In the Table 1 are given pinout configuration on NRF24L01 module.

Table 1. Pinout configuration on 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, or else it will disable the SPI
5	SCK	Serial Clock	Provides the clock pulse using which the SPI communication works
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 it 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 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 coverage can be in distance of 100 meters (200 feet), which makes it a great choice for all wireless remote controlled projects.!!!!!!

The module operates at 3.3V, hence 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. Hence 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 **SPIcommunications**. These modules can either be used with 3.3V microcontroller or a 5V microcontroller with SPI port. The complete details of usage of this module through SPI

is given in the data sheet below. The circuit diagram in the Figure4 shows that the module should be interfaced with the microcontroller.On Figure 4 is shown the usage of 3.3V microcontroller, 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.

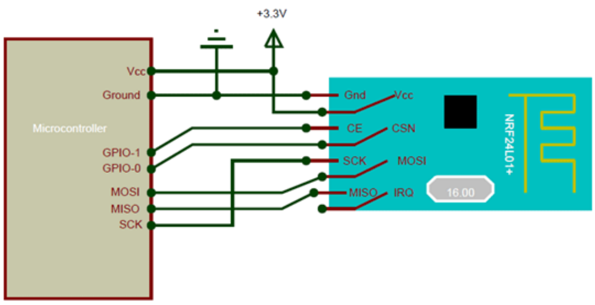


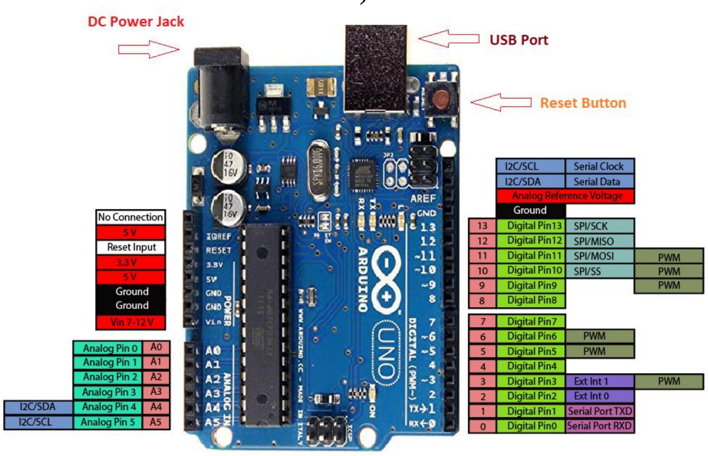
Figure 4. NRF24L01 module interfaced with a microcomputer

With help of these libraries N**RF24L01** can be easily interfaced with Arduino**,** with 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 **NRF24L01module** is a bit tricky to use especially since there are many cloned versions in the market. In case of troubleshoot, 10μF and 0.1μF capacitors should be added parallel to source Vcc and Ground pins. Also, the 3.3V supply should be clean and does not have any noise coupled in it.

b) Microcomputer ATmega 328P

The Arduino Uno is an open-sourcemicrocontroller board based on the Microchip ATmega328P microcomputer 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.

a.)



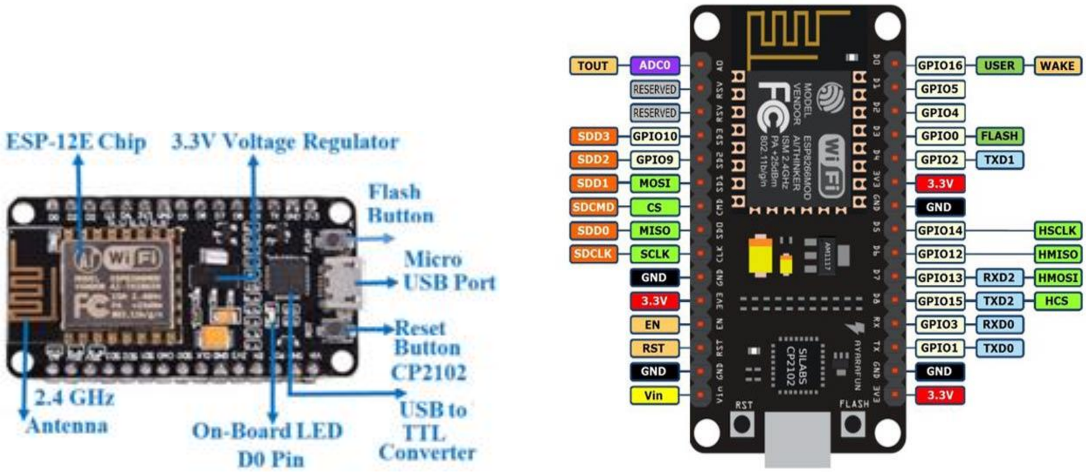
b.)

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

The word "uno" means "one" in Italianand was chosen to mark the initial release of Arduino Software. The Uno board is first in a series of USB-based Arduino boards; The Uno board and version 1.0 of the Arduino IDE were the reference versions of Arduino, which have now evolved to newer releases. The ATmega328P on the board comes preprogrammed with a bootloader that allows uploading new code to it, without the use of an external hardware programmer (Stefanov,2021). In Figure 5 a) is shown electronic board of Arduino Uno with build Atmega 328P microcomputer and in Figure 5 b) are shown its pinouts. The MASTER station, unlike the SLAVE station as seen in Figure 1 and 2, has yet NodeMCU 8266-12e node.

c.) Microcomputer NodeMCU ESP8266-12e

The NodeMCU ESP8266 development board comes with the ESP-12E module containing ESP8266 chip having 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 make 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 the Figure 6 is shown NodeMCU ESP8266 and its pinout.



a.) b.)

Figure 6. 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.

An essential part of the designed prototype SCADA system is the SCADA CDJ-Supervisor, so below follows a brief description of this software package, which is a product of Omron.

Design of the SCADA

The SCADA is made in Omron CX-Supervisor software, (Myomron). CX-Supervisor is dedicated to the design and operation of PC based visualization and machine control. It is not only simple to use for small supervisory and control tasks, but it also offers a wealth of power for the design of the most sophisticated applications. CX-Supervisor boasts powerful functions for a wide range of PC based HMI requirements. Simple applicationscan be created rapidly with the aid of a large number of predefined functions and libraries, and even very complex applications can be generated with a powerful programming language or VBScript. CX-Supervisor has an extremely simple, intuitive handling and high user friendliness. CX-Supervisor runs on standard PC desktop computers running Microsoft Windows. CX-Supervisor is intuitive and easy to use and allows the developer to rapidly configure, test and debug a project. CX-Supervisor comprises two separate executable Windows programs, CX-Supervisor Development environment and CX-Supervisor Runtime environment. Applications are created and tested using the development environment and then delivered as a final customer application with the runtime environment. The runtime-only environment may only be used for executing an application previously generated using the development environment. It is not possible to generate a new runtime application using the runtime environment. In the Figure 7 is shown connection between sensor hardware, microcontroller and CX-Supervisor SCADA.

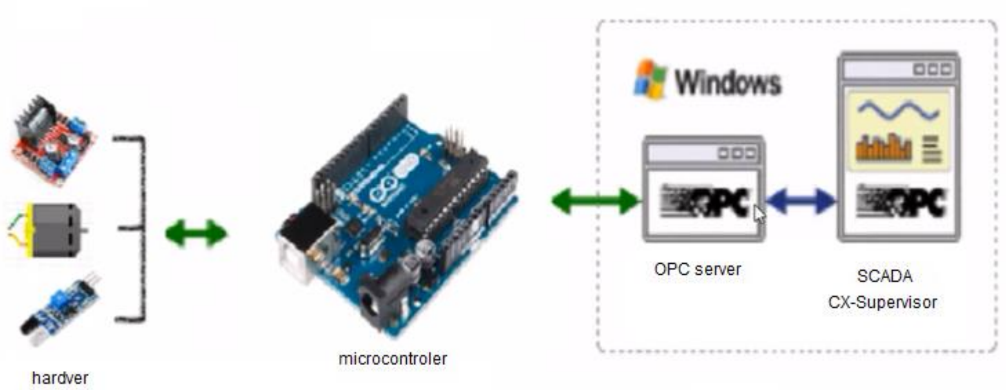
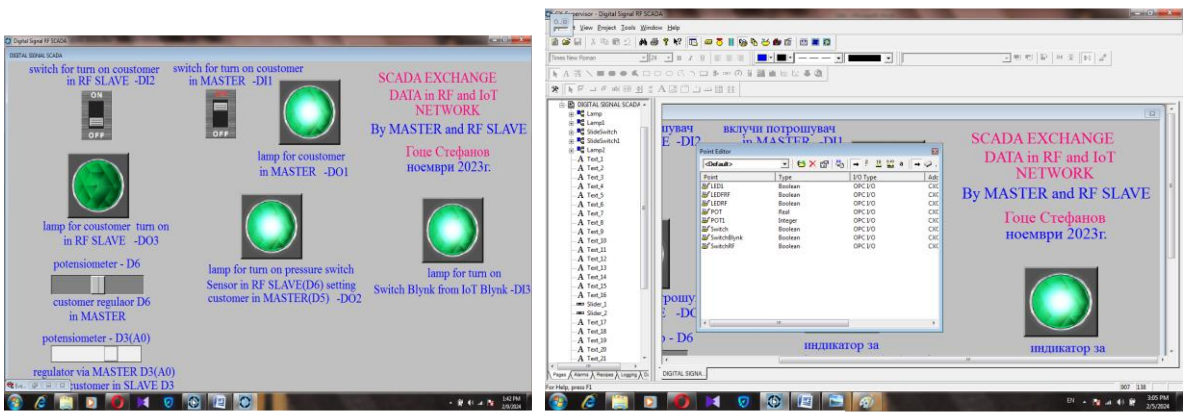


Figure 7. Connection between sensor hardware, microcontroller, and CX-Supervisor SCADA

a.) *Setting up Graphic Symbols*

The first thing to do is to set up graphic symbols. Now that the project exists with its own page, the graphic objects can be constructed and added to the page, Figure 8 a).



a.) b.)

Figure 8. a.) Setting graphic symbols, b.) Setting variables for graphical symbols

The graphics editor uses a Graphic Object toolbar and a floating window known as the Palette to construct and control objects on the page. These are very easy to use. Several small icons are visible on the Graphic Object toolbar - each one representing one of the graphical objects with which an application can be constructed. Some of the objects are graphical primitives - straight lines, ellipses, rectangles; some are rather more advanced - such as the gauge object, which has built-in functionality.

b.) *Setting up Variables for Graphical Symbols*

For each of the graphic symbols, a point variable with the appropriate size and unit is created, Figure 8 b). These variables correspond to the variables in the Arduino code.

c.) Setting Grafical Symbols with Variables

Finally, each graphic symbol is associated with a corresponding variable. In the Figure 9 is shown SCADA screen with defines variables.

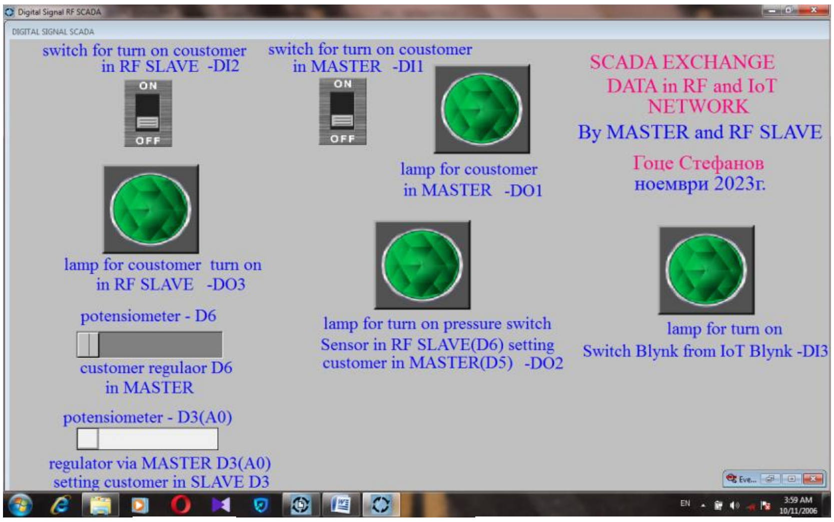
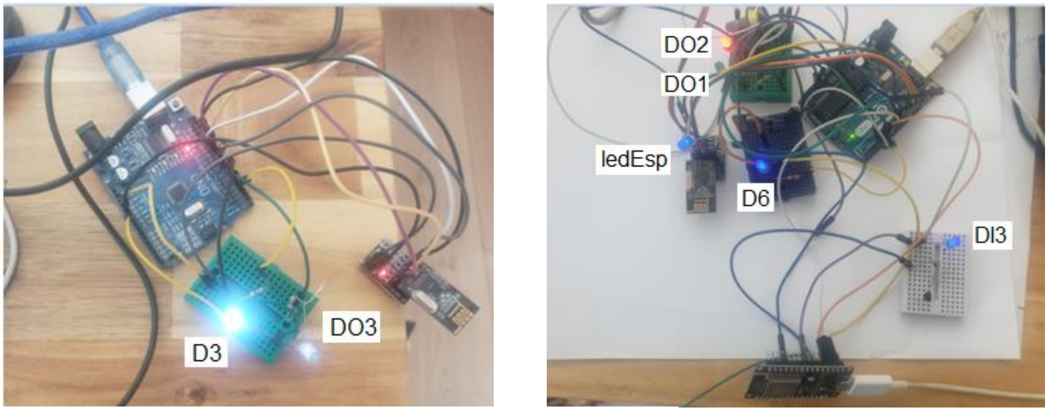


Figure 9. SCADA exchange data system screen with defines variables

SCADA screen for this prototype SCADA exchange data consists of the following elements:
Switch for turn on customer in RF SLAVE - DI2, switch for turn on customer in MASTER - DI1, lamp for indication turn on customer in MASTER - D01, lamp for indication turn on customer in RF SLAVE - D03, lamp for indication turn on pressure switch sensor in RF SLAVE D6 (causes turn on customer in MASTER - D02), lamp for turn on switch blynk from IoT Blynk - DI3, potentiometer - D6 which regulates analog PWM output signal D6 in MASTER station, potentiometer - D3 which regulates analog PWM output signal D3 in SLAVE station.

Experimental Results

Figure 10 a) shows the prototype on the SLAVE station, and Figure 10 b) shows the prototype on the MASTER station.



a) b)

Figure 10. Prototype on design SCADA exchange data system: a) prototype on SLAVE station, b) prototype on MASTER station

Figure 11a shows the screen of the design SCADA exchange data system and in Figure 11b is shown prototype on SLAVE and MASTER station when the SCADA screen is as in the figure 11a.

a.) b.)

Figure 11. a) Screen of the design SCADA exchange data system and b) prototypes on SLAVE and MASTER station when the SCADA screen is as in the figure 11 a)

In Figure 11 a) SCADA screen indicates that they are currently turn on: lamp for indication turn on customer in MASTER - D01, lamp for indication turn on pressure switch sensor in RF SLAVE D6 (causes turn on customer in MASTER - D02), lamp for turn on switch blynk from IoT Blynk - DI3, potentiometer - D6 which regulates analog PWM output signal D6 in MASTER station is is set to 50 % duty cycle, potentiometer - D3 which regulates analog PWM output signal D3 in RF SLAVE station is set to 50 % duty cycle.

A comparison of Figure 11 a) and b) shows that the LEDs in Figure 11 b) are in a state that is defined by the state of the elements of the SCADA screen. Figure 13 shows a routing diagram to illustrate the connection of the signal exchange between the SCADA screen, MASTER station, SLAVE station and the Blink Cloud.
On the Figure 12 a) are shown the regulated one analog PWM output signal D3 in RF SLAVE station, for illustrations for verification of the work of the designed SCADA system, when potentiometers in SCADA screen D3 is set to 50 % duty cycle, and Figure 12 b) the same thing when potentiometers in SCADA screen D3 is set to 90 % duty cycle.

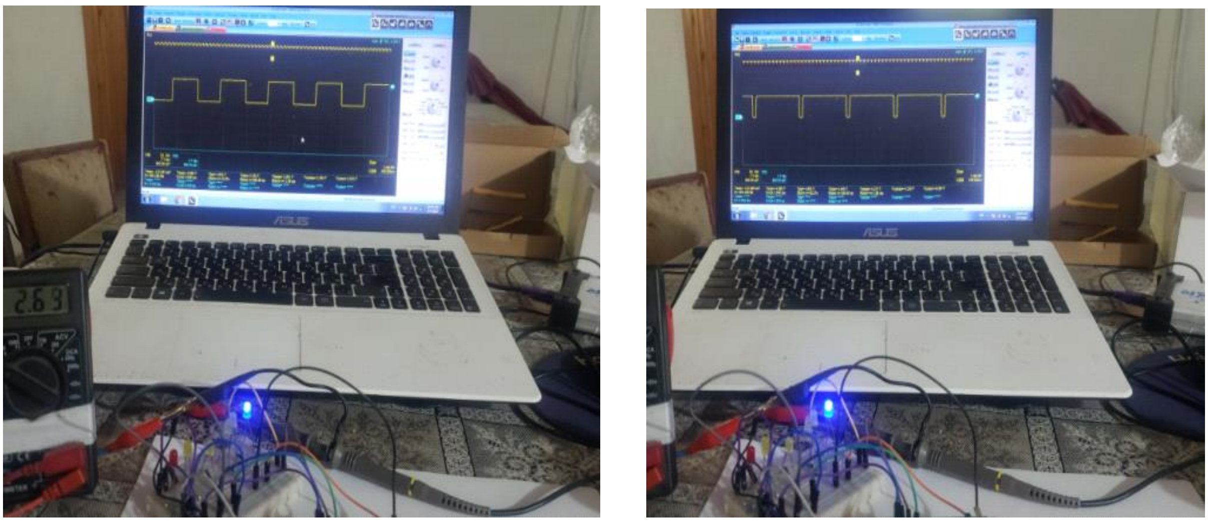


Figure 12. Verification the work of the designed SCADA system a.) when analog PWM output signal D3 in RF SLAVE station signal is 50 % and b.) when analog PWM output signal D3 in RF SLAVE station is 90 %

From Figure 12 a) also can be seen that led diode D03 (in RF SLAVE station) is on and is at medium brightness, the digital meter shows a value of 2.69 V, the waveform of the oscillogram is with a duty cycle 50 %. From Figure 12 b) it can be seen that D03 is on and is at high brightness, the digital meter shows a value of 4.57 V, the waveform of the oscillogram is with a duty cycle 90 %.

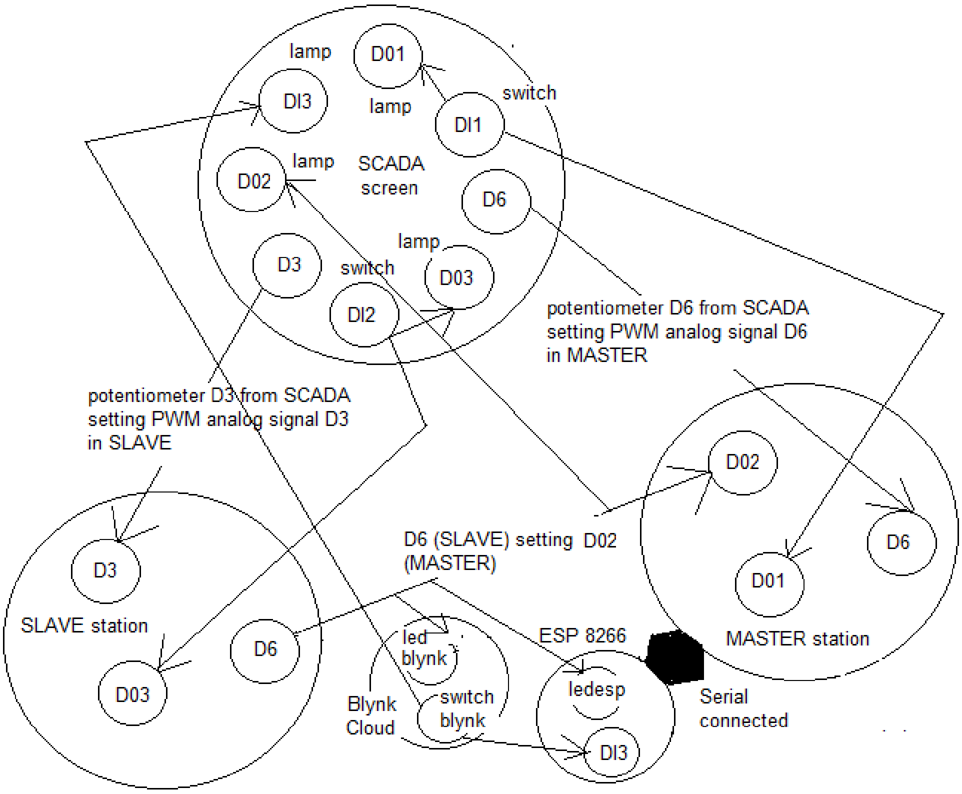
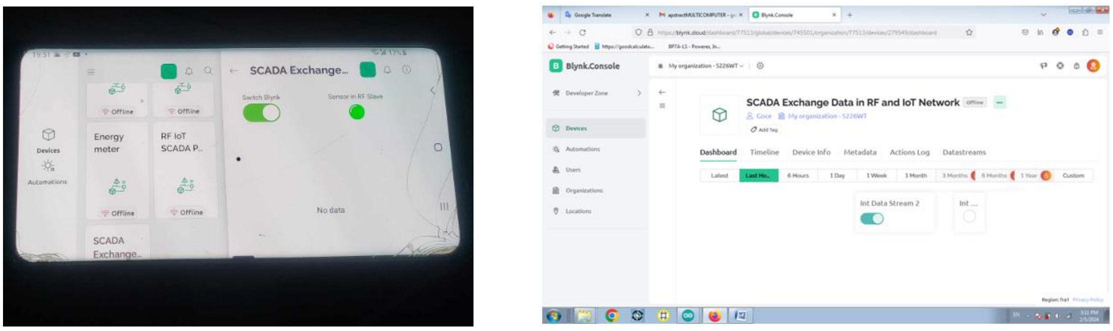


Figure 13. Routing diagram to illustrate the connection of the signal exchange between the SCADA screen, MASTER station, SLAVE station and the Blink Cloud

Figure 14 a) shows a data screen on a mobile device in which the data was transferred from a SCADA exchange data system in the IoT network, and Figure 14 b) represents a screen on the IoT Blynk cloud network (Stefanov, 2023).



a) b)

Figure 14. The screen on the exchange data from SCADA system in IoT network: a) screen on mobile device, b) screen on IoT Blynk cloud network

Turn on Switch Blynk in the Figure 14 a) shows that the Blink cloud turns on the LED DI3 (Figure 11 b)) in the MASTER station and turn on LED Sensor in RF Slave in the same Figure 11 a) shows that the pressure switch D6 (Figure 2) in the RF SLAVE is turned on.

Conclusion

The paper is designed as an experimental prototype on SCADA system for exchange data between two remote industrial plants. One measuring point is marked as SLAVE, the other is marked as MASTER station. The two measuring points are connected to each other by RF communication. The tested nrf24l01 modules provide the possibility of remote transmission of signals up to 5 km in free air. SLAVE and MASTER stations accept digital and analog signals and exchange them among each other. SCADA system and WIFI interface are embedded in the MASTER measuring point. The SCADA system participates in visualization and data exchange between SLAVE and MASTER stations, as well as data exchange in the IoT network. Such a solution provides the possibility of distribution and control of process data in remote industrial plants from any measuring point (SLAVE or MASTER station). Additionally, the proposed system also provides the possibility for the distribution of obtained data in IoT cloud computers and mobile smart devices (mobile telephone, tablet, etc.).

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as oral/poster presentation at the International Conference on Basic Sciences, Engineering and Technology (www.icbaset.net) held in Alanya/Turkey on May 02-05, 2024.

References

Atmel.(2015). 8-bit AVR microcontroller with 32K bytes ın-system programmable flash. Retrieved from *Atmel-7810-Automotive-Microcontrollers-ATmega328P_Datasheet. pdf*.

Bennett, S., & Linkens, D.A.(1982). *Computer control of industrial processes*. Stevenage: Peregrinus.

Citkuseva -Dimitrovska, B., Golubovski, R., Spasevska, H., Stefanov, G., & Kukuseva, M. (2021). Investigation of efficiency aspects in 3x3 photovoltaic plant using model of shading. *First International Conference ETIMA, 1*(1).

Hor, C. L., & Crossley, P. A. (2005). Knowledge extraction from intelligent electronic devices. In *Transactions on Rough Sets III* (pp. 82-111). Berlin, Heidelberg: Springer.

Stefanov, G., Kukuseva -Paneva, M., & Stefanova, S. (2023) 3-phase smart power meter implemented in RF network. *Balkan Journal of Applied Mathematics and Informatics, 6*(1), *25-37*.

Stefanov, G., Kukuseva, M., & Stefanova, E. (2021). Design of an intelligent Wi-Fi sensor network. *Balkan Journal of Applied Mathematics and Informatics*, *4*(1), 17-26.

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To cite this article:

Citkuseva-Dimitrovska, B., Zafirov, E., & Stefanov, G. (2024). SCADA system for process data exchange in master slave RF and Iot network. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)*, *28,* 554-564.