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The Utilization of Wireless Networks and Mobile Applications in the Control of Power Electronics Converters

Abstract. *The paper presents the implementation idea of remote control of power electronics converters by the use of wireless communication, such as Bluetooth and Wi-Fi, as well as a mobile application. The main aim of the conducted research was to propose the MIT App Inventor programming environment as a mobile application interface that enables safe control of the electric drive in an open loop. The developed control strategy has been tested when used to control the rotational speed of a squirrel cage motor supplied by a three-phase inverter.*

Streszczenie*. W artykule przedstawiono koncepcję realizacji zdalnego sterowania przekształtnikami energoelektronicznymi z wykorzystaniem komunikacji bezprzewodowej typu Bluetooth i Wi-Fi oraz aplikacji mobilnej. Głównym celem przeprowadzonych badań było zaproponowanie środowiska programistycznego MIT App Inventor jako interfejsu aplikacji mobilnej, umożliwiającego bezpieczne sterowanie napędem elektrycznym w pętli otwartej. Opracowana strategia sterowania została przetestowana przy sterowaniu prędkością obrotową silnika klatkowego zasilanego z falownika (**Wykorzystanie sieci bezprzewodowych i aplikacji mobilnych w sterowaniu przekształtnikami energoelektronicznymi**).*

Keywords: wireless remote control, mobile application, Arduino, converter, electric machine.
Słowa kluczowe: bezprzewodowe zdalne sterowanie, aplikacja mobilna, Arduino, przekształtnik, maszyna elektryczna.

Introduction

Currently, along with the continuous development of technology, the Internet has encompassed almost all branches of modern life involving industry [1,2,3]. What is more, devices which are controlled wirelessly are becoming very popular and nearly every person has a mobile device acting as an interface thus allowing a control over other objects [4,5]. Nowadays, people live in a period of rapid development of the Internet of Things (IoT), which constitutes an intelligent global network and constitutes a strategy for extending Internet connectivity beyond electronic devices, such as laptops and smartphones, to any type of household appliances, for example, washing machines, ovens [3,6]. Along with the development of the IoT, networking technologies, such as Wi-Fi, Bluetooth, and long-term evolution (LTE) have occurred [7,8]. This, in general, has provided an opportunity to manage processes from the level of a mobile application as they serve people and ensure support in intelligence systems including healthcare, transportation, smart houses, smart agriculture, smart cities and smart grids [9]. The latter is characterized by the capability of two-way communication of both electricity and data [10].

The applicability of mobile devices with wireless transmission to control industrial automation devices, such as electric drives, seems to be an interesting solution, especially as it allows maintaining a safe distance from a device under operation. Additionally, the use of microcontrollers enables sending and collecting data from sensors of various types in a dispersed manner. Moreover, remote control improves control efficiency by reducing the number of wires thereby the problem of their arrangement. However, wireless transmissions are not devoid of disadvantages since they are exposed to the impact of external factors, which are mainly other radio systems or electromagnetic disturbances of various origins.

Another aspect is the mobile application itself as its properties determine the attending of a system to some extent. The safety of the operator as well as the device under control from the level of such an application often depends on whether it is written in accordance with the accepted standards and on its ergonomics. Applications which are used to control the operation of electric motors or other industrial devices have particularly higher functional and safety requirements than ones that can be downloaded from application stores [11].

The concept of open-loop control of an electric drive is presented in a graphical form in Figure 1. It indicates the problems which are related to a wireless electric drive control system. They encompass the interface of the mobile application, which should be precise and ergonomic, specifics of wireless transmission technology related to the distance between the mobile device that provides the interface for the system user and the object itself, and the requirements for open-loop control including the verification of connection continuity and information coupling.

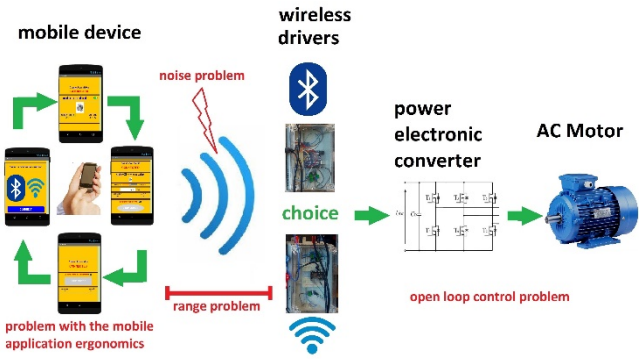

Fig.1. Schematic diagram of an open-loop remote control system of induction motor

This paper focuses on the remote control of electric drives based on wireless communication and mobile application. The paper consists of descriptions of important functionalities that a mobile application ought to provide and the programming environment which can be utilized to prototype such an application by engineers whose programming competencies are basic. Particular stages of the conducted research include the implementation of the remote control of two wireless transmissions and the development of a mobile application in the MIT App Inventor environment. The presented remote control system has been tested on a three-phase two-level voltage source inverter (VSI) with a three-phase squirrel cage motor. This work is an extension and further stage of research presented in [12].

Wireless transmission technologies

There are two main wireless transmission technologies used in remote control strategies: Wi-Fi and Bluetooth. The

former belongs to the 802.11x standard, which describes WLAN local networks. It utilizes radio waves for both communication and data transfer using frequency bands 2,4 GHz and 5 GHz. Utilizing a Wi-Fi module is noticeably suitable because of bandwidth, high speed and large distance coverage. The typical ranges of Wi-Fi transmission in an open area and inside buildings are about 100 meters and 30-50 meters, respectively.

Bluetooth belongs to the open specification of computer and telecommunication technology IEEE 802.15.1, which enables wireless communication over short distances within a range of about 10 meters [8]. Due to this, it is mainly used in order to replace cable connections of ICT (information and communication technology) and computer devices in close vicinity of the computer. Bluetooth wireless communication creates a WPAN (IEE 802.15) Personal Area Network (WPAN), in which devices, such as mobile phones, smartphones, digital cameras, change their location in accordance with the users' movement. Table 1 presents a comparison of selected parameters of the applied wireless transmission technologies with the technologies used in IoT [13].

Table 1. Summary of selected parameters and features of the Wi-Fi and Bluetooth transmissions

	Typical for mobile devices		**Typical for IoT**	
Feature	Bluetooth	Wi-Fi	LoRaWAN	ZigBee
Bandwidth	Low	High	Very Low	Very Low
Hardware equipment	Bluetooth adapter only	Wi-Fi access point and Wi-Fi adapters required	Dedicated devices	ZigBee Coordinator, ZigBee Route, ZigBee End Device
Topology	Point-to-point	Point-to-point, broadcast, and mesh networking	Star-of-stars	Star, Tree, Mesh
Range	10 meters	30-50 meters in buildings, 100 meters in open field	10-15 km	10-100 meters
Security	Less secure	More secure	More secure	More secure
Power consumption	Small power consumption	Much more power consumption	Very small power consumption	Very small power consumption
Frequency	2.4 GHz	2.4 GHz and/or 5 GHz	169 MHz, 433 MHz, 868 MHz (Erupe) 915 MHz (North America)	2.4 GHz 868 MHz and 915 MHz (selected regions of the world)
Speed	Slow - about 1 Mbps	Fast - about 1 Gbps	Slow – about 50 kbps	Slow – about 40-250 kbps
Flexibility	Limited number of users	Large number of users	Very large number of users	Limited number of users
Ease of use	Very popular and widely available Simply and easy to use	Very popular and widely available Complex software and hardware as well as configuration required	Simply and easy Difficult access to technology - it is developed by about 500 companies in the world to use	Simply and easy to use Difficult access to technology - it is developed by about 150 companies in the world

The wireless transmission technologies utilized in the IoT differ from Bluetooth and WiFi technologies. The main difference, particularly, concerns the range, which is usually larger in the case of LoRaWAN, and the bandwidth, which is very low in the case of solutions intended for the IoT. Moreover, wireless technologies exploited for the IoT are mainly characterized by small energy consumption, simplicity of both implementation and use as well as a high level of security.

Fig.2. The interface of the developed mobile application with sequentially switched screens; from the left: a) Establishing a connection (Bluetooth or Wi-Fi); b) Enabling control; c) Motor rotational speed control (using a slider or entered value) with an emergency stop; d) Motor shutdown and disconnect

Programming environment dedicated to mobile application

Among various technologies enabling the creation of mobile applications, the most popular are tablets and smartphones which are supported by Android or iOS systems. The article presents an application written in MIT App Inventor as it gives engineers a great opportunity to provide their projects' users with a modern interface. Simultaneously, this program offers a graphical interface that supports the work of an engineer ensuring an easy way of designing and programming applications since it utilizes Scratch programming language.

The implementation of remote control of the power electronics converter requires the development of at least two types of programs. One of them should support a digital platform which is installed at the converter and directly transmits control signals to the power converter. The other, however, is required by a mobile device and

constitutes an application that is a graphical interface designed for a system user. In both versions of used drivers, the software for digital platforms has been written in the Arduino IDE environment as both Arduino UNO and NodeMCU v3 are compatible with it and have appropriate libraries.

The utilization of wireless transmission and mobile application in control

The verification of the proper operation of both the application and wireless transmission was performed in the power electronics laboratory stand presented in Figure 3.

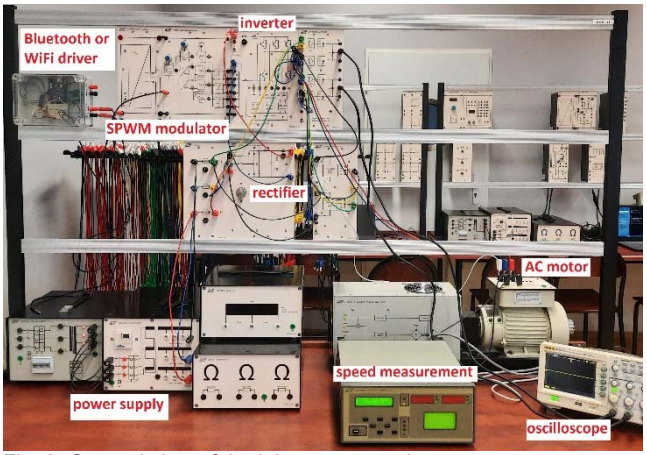

Fig. 3. General view of the laboratory stand

The developed control application has been used to control the rotational speed of a three-phase squirrel cage motor supplied by a three-phase VSI inverter, whose communication with a mobile device was via a Bluetooth or Wi-Fi module. The frequency converter supply line-to-line voltage was 3 x 220 V, while its frequency was equal to 50 Hz. The applied control system utilizes the scalar method to control the rotational speed of AC motor (Fig. 4).

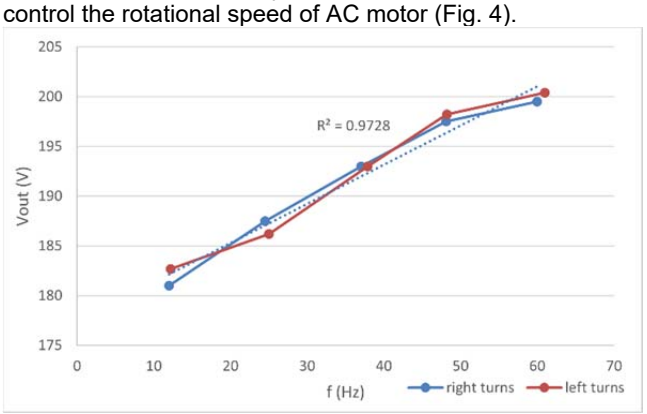

Fig.4. Voltage-frequency dependence obtained for the scalar method of VSI control, acquired during tests of wireless transmissions application

The parameters of SPWM modulation (the frequency and amplitude of reference sinusoidal waveform) in the system are dependent on the value of control voltage in a linear way. The range of control voltage is equal to -10÷10 V, which corresponds to the sinusoidal waveform frequency 0÷60 Hz and the scope of amplitude modulation factor 0÷1 for both directions of motor rotation. The frequency of the carrier signal has been set to 1 kHz. The control is performed in an open loop and does not include the feedback from the motor rotational speed value. Classically, the value of the control voltage is changed manually by using a traditional knob. The remote control has been conducted in such a way that a constant numerical value has been sent from the application to the microcontroller in order to generate PWM signal. Its average value has been passed to the controller which defines the parameters of control signals. The system that is responsible for converting the PWM voltage to its average value is LCT-167 PWM. Figure 5 presents the diagrams of electronic circuits realizing Wi-fi and Bluetooth wireless transmissions.

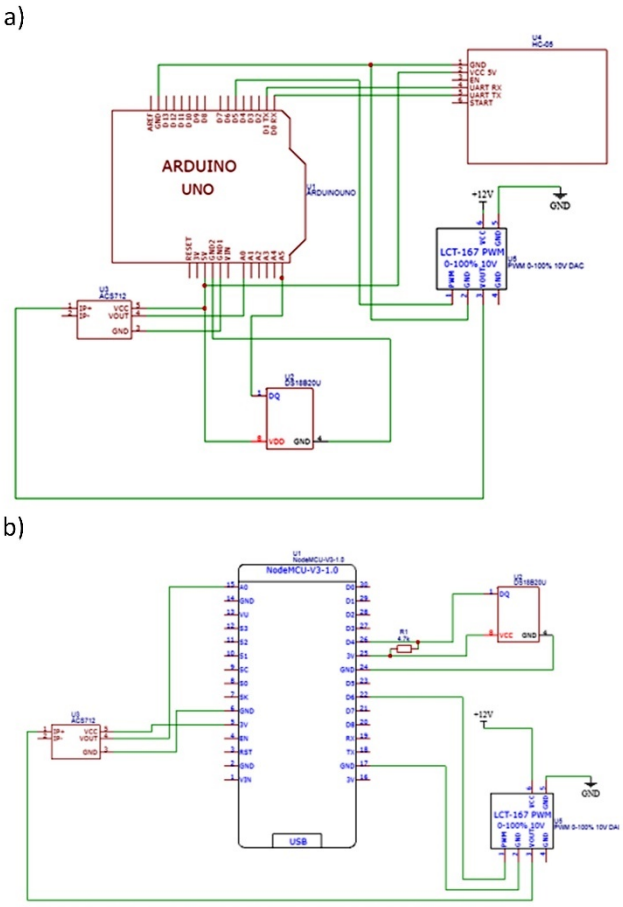

Fig.5. Schematic diagram of the control system using a Bluetooth (a) and WiFi (b) transmission modules

Figure 6 depicts the characteristics of the rotational speed of the squirrel-cage motor as a function of changes in the reference voltage, which has been generated by the modules shown in Fig. 5. Figures 7 and 8 present the exemplary waveforms of the VSI input and output currents and voltages as well as their spectra for the fundamental frequency of 50 Hz.

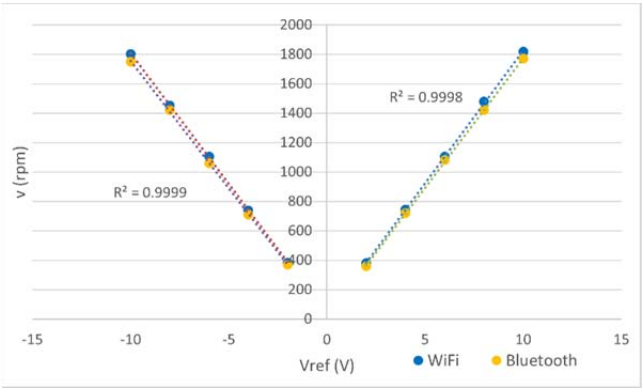

Fig.6. Comparison of results obtained by using WiFi and Bluetooth transmission in remote control of AC motor rotational speed

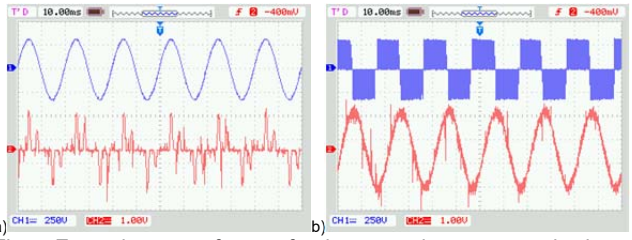

Fig.7. Exemplary waveforms of voltages and currents at the input (a) and output (b) of the converter used in the experiment

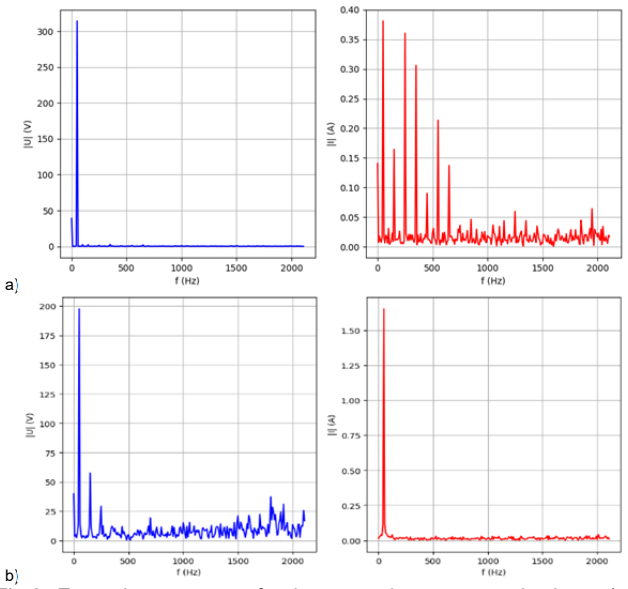

Fig.8. Exemplary spectra of voltages and currents at the input (a) and output (b) of the converter applied in the experiment

The signal frequency spectra have not affected the wireless transmission as the frequency bands of the electrical signals differed from the ones utilized in the wireless transmissions. Hence, the signals emitted by the converter have no influence on the transmission of the control signals generated by the developed wireless controllers.

Table 2. Dependencies of system performance quality indicators on the distance from the controlled device

Distance	2 [m]	8 [m]	12 [m]
Object visibility	Very good	Good	Poor
Control with the use of Bluetooth	Full control over the object. Continuous connection. Smooth control. Control parameters are updated regularly.	Full control over the object was not preserved. Intermittent connection. Intermittent control. Control parameters were not updated regularly.	There was no control over the object. No connection and no control possible. No information about control parameters.
Control with the use of Wi-Fi		Full control over the object. Continuous connection. Smooth control. Control parameters were updated regularly.	

The implementation of wireless communication in the remote control system has been tested in dependency on the distance of the mobile device from the motor drive and its supply. When testing, other machines in the laboratory were under operation to obtain conditions similar to those present in the production hall. Bluetooth and Wi-Fi modules operation have been verified at the distances from the object equal to: 2, 8, and 12 meters. Such values have been chosen on account of the practical utilization of the system and the visibility of the object under control, as well. If the object had been out of sight, the control system should have included a visual preview, for example from a camera. Significant indicators of the proper operation of the tested control system are shown in Table 2.

Conclusions

The results achieved in the performed tests have confirmed that it is possible to control the rotational speed of an AC motor supplied by a three-phase VSI with the application of remote control system using wireless communication. Both Wi-Fi and Bluetooth methods provide control accuracy at the same level. However, the module communicating via Wi-Fi ensures the opportunity to control the system from anywhere since it covers longer distances than Bluetooth. The only requirement to connect to the controlled object is owning a smartphone with a mobile application and access to the internet. Mobile applications are becoming the basic GUI interface for modern technical systems in various branches of engineering. The proposed form of the application has indicated important issues in its design and ergonomics. The presented remote control system can be suitable for some industrial requirements and applications.

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