ANDRIOD-BASED REMOTLEY ACCESSED PLC CONTROL SYSTEMS

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ABSTRACT
The evolution of the Internet has led to a great influence on the software industry and the development of companies. Recently, networked control systems are widely adopted in industry because of the big facilities provided for plant control. Also, accessing the local control systems and remote telemetry units (RTUs) remotely became a primary requirement. Therefore, this paper presents a method for connecting a PLC (Programmable Logic Controller) to a server and hence to the internet for the sake of remotely access. The work starts with building a local network for interconnecting a PLC with its Ethernet extension, an HMI (Human Machine Interface) touch screen, a supervisory PC, a smartphone, and a hub/switch. After that, the PC is connected to the internet and the server program is updated to get a global network that can be accessed via the internet worldwide without the need for public (real) IP. A web site is designed and used through the PC to reach the PLC system. The HMI touch screen is programmed with SoMachine software provided by Schneider Electric. An Android application is also developed with Java and published in google play of Android smartphones in order to add another means for controlling the PLC control system. PID (Proportional-Derivative-Integral) control algorithm is designed as a function block for home temperature control. The home temperature control is adopted just as a case study to prove the work of the overall control system.

Keywords*:* Web server, PLC, Android, HMI, PID, FBD, IoT.

منظومات سيطرة نوع PLC مسيطر عليها عن بعد وباستخدام انظمة الاندرويد

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الخلاصة
ان تطور الانترنت ادى بشكل ملحوظ الى تعزيز صناعة البرامجيات، ابتداءا من سهولة بناء الاعمال الخاصة واستمرارا بالعمليات التي تستخدمها الشركات للتطوير والتوزيع والدعم لمنتجاتها. لقد اصبحت انظمة السيطرة الشبكية في السنوات الاخيرة واسعة الاستخدام في الصناعة عطفا على السهولة والمرونة في عمليات السيطرة وعمليات الوصول الى الوحدات الطرفية البعيدة عن بعد. لذلك يتبنى هذا البحث طريقة لربط منظومة سيطرة رقمية مبرمجة نوع PLC وخادم لغرض الوصول والتحكم والاشراف على نظام حرارة منزلي عن بعد وعبر الانترنت. يبدأ العمل من بناء شبكة محلية لربط نظام السيطرة من خلال توسعة ايثرنت مع شاشة لمس تسمى HMI ولابتوب بالاضافة الى تلفون نقال تربط جميعا لراوتر متصل بالانترنت لربط الشبكة المحلية بالشبكة العالمية. يتم الوصول للشبكة المحلية من خلال تطبيق اندرويد وكذلك صفحة ويب صمما للسيطرة وعرض بيانات الحرارة المنزلية وبدون الحاجة (وهذا هو المهم) الى رقم IP حقيقي. استخدم برنامج ال SoMachine من انتاج شركة شنايدر لبناء ال HMI وكذلك لبرنامج السيطرة FBD للمسيطر. اما تطبيق اندرويد فقد بني باستخدام Java Eclipse و SDK للحصول على الواجهة الرسومية لعملية

العرض والسيطرة ونشر على سوق **Play** ليتاح للاستخدام. اما صفحة الويب فقد صممت باستخدام (**HTTP, CSS, PHP, SQL, etc**) وربطت بالمنظومة من خلال سيرفر مجاني (**ATspace**) يقدم خدمات كاملة لعمليات تبادل البيانات المختلفة. صممت المنظومة بحيث تكون عامة لاي تطبيق سيطرة اما بالنسبة لمنظومة الحرارة فهي مجرد **Case Study** لاثبات نجاح العمل.

الكلمات المفتاحية: مسيطر منطقي مبرمج، اندرويد، وسائط ماكنة-انسان، مسيطر ثلاثي الحدود، المخطط الكتلي، انترنت الاشياء

NOMENCLATURE

API	Application Peripheral Interface
CSS	Cascading Style Sheets
DHCP	Dynamic Host Configuration Protocol
FBD	Function Block Diagram
GUI	Graphical User Interface
HMI	Human Machine Interface
HVAC	Heating, Ventilation, and Air Conditioning
HTML	Hyper Text Markup Language
IP	Internet Protocol
IoT	Internet of Things
JSON	JavaScript Object Notation
LD	Ladder Diagram
LAN	Local Area Network
MWA	Mobile Web Application
OS	Operating System
PID	Proportional Integral Derivative
PC	Personal Computer
PLC	Programmable Logic Controller
PHP	Hyper Text Preprocessor
RTU	Remote Telemetry Unit
SOAP	Simple Object Access Protocol
SDK	Software Development Kit
SQL	Structured Query Language
SCR	Silicon Controlled Rectifier
XML	Extensible Markup Language

1. INTRODUCTION

New types of programming languages and development tools are required for client-server and web-based applications, (**Anthony, 2011**). Open source software must be used particularly at the infrastructure level for applications and Internet-based tools are adopted for collaboration and applications development. Continuous advances in mobile and cloud computing have a large effect on many types of systems and products. The effect of the Internet all over the world is very huge and has a big revolution of communications among organizations, individuals, and industrial systems, that made it possible for people to buy everything they need online, enabled the creation and expansion of a large number of businesses, and made industrial monitoring and control possible. Companies nowadays support their products over the Internet through online supervision and control. Many existing business practices and industries have been canceled because of the internet and web applications. Development of the Internet affects strongly the software industry. One of the goals of this paper is to adopt the forces that have globally transformed the industry. The proposed overall system can be categorized as one of the applications of the internet of things (IoT). IoT is described as interconnecting things like smartphones, Internet TVs, PLC controllers, sensors and actuators to the Internet and to each other's smartly, **(Kortuem et al, 2010)**. Building IoT has advanced significance many years ago since it has provided a new direction to the world of information, communication, and control technologies. The number of devices connected to the Internet is expected to reach billions by the year 2020, **(Hilton, 2012)**. Hence, anyone, anytime and anywhere can connect to things leading to creation an advanced dynamic network of IoT. It can also be applied to create a new principle and wide development field for industrial applications' monitoring and control as the proposed work of this paper will do.

On the other side, smartphone is chosen because it is a device that has many benefits such as: accessing the web sites, has an open source operating system, has different wireless capabilities, and has a touch screen for I/O. In other words, the smartphone is a computer with capabilities of a phone and a computer in one device package. The technology applied with smartphones is known as Mobile Web Application (MWA), **(Goodwin, 2010)**, which is the easiest application to learn, standardized, most available, and can be distributed. MWA is a platform capable to be run on smartphones, using the standard protocols of web applications of computers, **(Fling, 2009)**. This cheap and reliable home control and monitoring unit uses a hidden web server without public (real) IP for controlling equipment remotely using a web page and Android based smartphone application. The presented system need not a dedicated computer server as compared to other systems and it uses a communication protocol to monitor and control the home devices by different types of control (analog or digital).

As a control application, PLC is used as a temperature controller. PLC is one of the famous digital control strategies that used effectively and efficiently in industrial, automotive, manufacturing and home automation systems. It is used in a various digital control applications because of its simplicity, robustness, flexibility, and reliability. PLC devices have many advantages such as: high computing capabilities and the ability to communicate using different protocols (RS232, RS485, and Ethernet). Complex and difficult control plants can be handled by a PLC, which combined two basic types of control systems: distributed and integrated. Components such as sensors, actuators, touch screen, etc. are connected via digital/analog I/O modules or through communication channels (ports). The PLC is suitable for complex solutions in the field of measurement and real-time control. The type of control algorithm designed in this work is a PID controller because of its wide acceptance in industry. The design of the PID algorithm for a temperature control system is implemented by function block diagram (FBD) and downloaded in a Zelio smart relay PLC. To prove the operation of this system, the PLC is equipped with temperature sensor LM35, and a small electric heater. The proposed automation control system is customizable i.e. it can be used for controlling any home or industrial plant connected to the PLC. The PLC is packaged with HMI touch screen, which provide local monitoring and control. Besides that, the monitoring and control is done with web page on a computer and Android smartphone remotely. This system covers the issue required in home and industrial wise applications, which is the availability of a facility to supervise and control systems and devices remotely via internet from anywhere by a computer or a mobile phone.

The paper outline is as follows: Section 2 is concerned with a list of some related works. In section 3, the proposed system architecture is explained. Section 4 provides the implementation of the system in software and hardware. Section 5 summarizes the main conclusions.

2. RELATED WORK

Smart homes and industrial automation can be described as important issues to provide some facilities such as: convenience, security, comfort, energy efficiency, and fully controllable. Addition of intelligence to home environment provides more quality for everyday life especially for disabled people. Significant development in home automation and smartness has been done couple of years due to big advancement in smartphones and tablets allowing vast connectivity, **(Rajeev, 2013)**. More popularity has been provided for home automation with the coming of the Internet of Things, **(Liu, 2013)**. Many studies have been presented for home automation systems using Bluetooth of the Android smartphones without Internet access e.g., **(Piyare et al, 2011), (Potts et al, 2012)**. The drawback of this type of systems is the small range of operation (about 100 m) the matter that made it unable to satisfy mobility. Some research papers presented home gateways to realize network interoperability and remote access for homes, **(Elshafee et al, 2012)** using Wi-Fi and computer web server. Another designs have also been presented, **(Sharma et al, 2012), (Rajabzadeh et al, 2010)**. They developed a special web server, database and a web page to connect and supervise home devices. The drawbacks of these systems are: **One**, using a PC increases the cost of installation and the energy consumption. **Two**, increasing cost resulting from development and hosting of web sites. A GSM communication for home equipment is also designed by, **(Onukwugha et al, 2013)** to send commands to home mobile that in turn controls appliances. In this type of systems, there is no graphical user interface (GUI) and users need to remember many commands required for home control. **(Tiago et al, 2015)** reviewed applications of mobile IP-based architecture in intelligent homes automation and security without the need for real deployment and examining. Some researchers have also introduced the use of web techniques, Simple Object Access Protocol (SOAP) and Representational State Transfer (REST) protocol for remotely access home automation systems e.g. **(Perumal et al, 2013)** presented an intelligent home management mechanism using Ethernet network that depends on XML SOAP standards. SOAP based web service is indeed has slower operation and higher Bandwidth. REST protocol is used as a Web-based interaction to control home appliances using HTTP caching and push messaging, **(Okan et al, 2014)**. They developed a web GUI to treat with the home appliances. Cloud computing has also been presented **(Dickey et al, 2012)** to make users able to control different appliances within home. In spite of that the aforementioned manuscripts have made clear contributions to the field of home automation, but they were mainly concentrated on switching and controlling home devices rather than remotely controlling and supervising home environment using sites and Android application without public IP, which is the work developed in this paper.

3. THE PROPOSED SYSTEM ARCHITECTURE

In order to satisfy the aforementioned flexibility and functionality for home monitoring and control, a new, independent, reliable, and cheap home supervisory system is performed using web services and Android app. The system contains a web server, Ethernet communication interface, Zelio PLC, PC computer, router (hub/switch) and Android compatible smartphone app. The system is generic means that different applications with minimal design complexity can be customized with capability of new thread creation in its software. The authorized persons can remotely control and monitor networked field devices at home or factory with smartphone supporting Wi-Fi and Java. A phone GUI is designed by Java app for accessing and controlling the desired devices at home via server overcoming the need for real IP. The infrastructure of the proposed system comes with three tiers: Home tier, Home Gateway (PC), and Remote tier as shown in **Figure1**. Remote tier is the authorized users accessing the system with smartphone app. Home tier consists of Home Gateway and the physical devices. Home Gateway provides data translation services between home environment and remote environment. The Home Gateway is simply a web server that manages and controls system components by enabling hardware interface modules to invoke their tasks. Hardware interface modules are connected with sensors and actuators across a PLC controller. The PLC system designed has a capability to control any home components and appliances such as: energy management; lightings, HVAC (heating, ventilation, and air conditioning); security systems: door locks, and gates; home temperature control, etc. Of course, the designed system has the capability to be used in industry. As a case study, the system is used for room temperature controlling in which there are a temperature sensor LM35, a simple heater (240VAC, 7A), and an electric fan.

4. SYSTEM DESIGN AND IMPLEMENTATION

The proposed home monitoring and control system is ubiquitous and contains three essential modules: the web server, interface modules and devices, and the software packages (smartphone app, FBD of the PLC, HMI). Temperature sensor, heater, and a PLC controller have been equipped with the proposed home control system. The subsequent sections describe the system implementation in detail.

A.SoftwareDevelopment

There are three parts for software designed to the proposed home automation system: server program, Android app, and PLC controller firmware. The server program is a web site designed with HTML, PHP, CSS, SQL, and JavaScript making use of free services provided by a free web hosting company (ATSPACE.COM). Data is exchanged between server and clients with HTTP protocol, JSON (JavaScript Object Notation) and XML services provided by the free server. Configuration stage and sensor/actuator control stage have been performed on control network to realize connection between remote used and the gateway. **Figure 2** shows a diagram of linking of the PLC control system to the Internet. The Gateway enters the configuration stage immediately after it is begin connection to the internet over http. During this stage the Ethernet port of the HMI touch screen connects to the Local Area Network (LAN) depending on static IP address. Static IP address is used instead of an IP obtained from Dynamic Host Configuration Protocol (DHCP) in order to get optimum communication. Reception of string commands from the web page or the smartphone app is translated into a suitable control action. These actions are control signal actuation or sensor reading.

Web services are easy to access using communication means and application programming interfaces (APIs). Two types of web services are available: Simple Object Access Protocol (SOAP) and Representational State Transfer (REST) **(Kumari et al, 2015)**. Both SOAP and REST are two standard protocols for IoT. REST is similar to SOAP but more lightweight scheme; hence it is used for web service that returns JSON responses to connect between the remote user and the web server. JSON is a lightweight means for information exchange that is easy for people to read and write. It is also easy for machines to produce messages instead of using XML. The web site designed for the desired task is displayed in **Figure 3.**

Several methods are there for building smartphone application such as Windows Mobile, Symbian, iOS and Android. Most smartphones support Android OS; therefore, it is adopted in the development of our application depending on JAVA programming language and the Software Development Kit (SDK). The designed smartphone app allows full interaction with the home control application. **Figure 4** illustrates the designed Java graphical user interfaces for our Android app. The smartphone app for home control and monitoring application of this work provides the following benefits to the user: 1) Remote access to the Home Gateway. 2) Reading sensor input 3)

Displaying PLC output 4) choosing among three types of control: PID, ON/OFF, and manual, and 5) Set-point setting. The user has to setup the port number and the IP address of the web server in the app to satisfy successful communication. Synchronization between the app with the web server should be satisfied to retrieve the actuator and sensor information. The communication between the PLC and HMI is satisfied with a cable connecting the RS485 port of the HMI to the SR3NET01BD Ethernet extension. The Ethernet port of the HMI is connected to the hub/switch to enter the LAN network.

B. Hardware Devices

The overall implementation diagram shown in **Figure 1** contains the following required hardware components:

1. LM35 temperature sensor: The LM35 is a low-cost high accuracy temperature sensor, with linear relationship between its output voltage and Centigrade temperature. It needs not any external calibration to provide accuracies of ±1⁄4°C at room temperature over a full 0 to +150°C range, **(National Semiconductor, 2000)**. In order to input the sensor to any of the PLC analog inputs, a signal conditioning circuit is required. The circuit amplifies the low output voltage of the sensor (0~1.5V) to the required range of the PLC analog input, which is 0~10V. The designed circuit with the LM35 sensor is shown in **Figure 5**.

2. Zelio PLC SR3B261BD: It is a low-cost high efficiency simple controller that can be used for several control applications, **(Schneider Electric, 2016).** It has 16 inputs, six of them are analog, and 10 relay outputs. The operating voltage is 24VDC, and the output relay voltage can be 24VDC or 240VAC. An Image for this device is shown in **Figure 6**.

3. Analog I/O extension module SR3XT43BD: To use Zelio Logic smart relay with analog I/O, it is fitted with analog I/O extension module having 10-bit resolution. It has three inputs; 0-10 V, 0-20 mA and Pt 100 type signals and the outputs produce 0~10V. By this arrangement, there are 30 I/O: 8 analog inputs and 2 analog outputs, **(Schneider Electric Catalog, 2011)**. **Figure 7** shows its image.

4. Ethernet extension module SR3NET01BD: It is compatible with all versions of Zelio SR3 series **(Schneider Electric: Datasheet, 2016)**. It provides a means for connecting the PLC with HMI or hub/switch or Modbus. **Figure 8** shows its image. It manages up to 4 connections simultaneously. Its IP address is configured as static as shown in **Figure 9.** Four input words (J1XT1 to J4XT1) and four output words (O1XT1 to O4XT1) are accessible via the function block (FBD) as shown in **Figure 10.**

5. Electrical SCR Actuator: The SCR power controller shown in **Figure 11** is designed to regulate AC power to the heater. It receives a 4~20mA analog signal from the Analog I/O extension module via a signal conditioning circuit designed to convert the 0~10V signal coming from the analog module to 4~20mA signal. This conditioning circuit is designed and displayed in **Figure 12.** The SCR is relaying the AC voltage to the heater from zero voltage to full voltage according to the control signal (4~20mA) applied. The original analog signal is produced from a PID controller designed and embedded inside the PLC. The PID controller is chosen here since it is a widely-used and industrial-wise controller that is easy to design and tune **(Emre et al, 2016)**. The PID control algorithm is implemented as a FBD by Zelio Soft 2 software provided by Schneider Electric and shown in **Figure 13.** Tuning of

its parameters has been done by trial and error and can be updated as required by HMI operator touch screen or by web or Android app. Real-time PID control response is measured and shown in **Figure 14.** The fine-tuned parameters are: K_p=2.49, K_i=0.000005, and K_d=330.

6. HMI touch screen Magelis HMIS5T: it is a Human Machine Interface product with the following specifications: 24VDC, 3.5 inches, color, TFT graphic touch screen with serial (RS485) and Ethernet ports, (**Schneider Electric: Magelis, 2012**). It is connected via the serial port to the PLC across the Ethernet communication module and connected to the hub/switch via the Ethernet port to make the PLC part of the LAN network. It is programmed as required with software called "Vijeo Designer" embedded in a software package called "SoMachine" produced by Schneider Electric, **(Vijeo Designer Tutorial, 2016)** as shown in **Figure 15**. There are five interfaces designed with Vijeo Designer to the HMI screen for the sake of local (site) control, some of them are shown in **Figure 16**.

7. Other accessories: There are some other accessories needed to complete the whole panel of the proposed system such as: 24VDC power supply, small heater, small Fan as a cooler, any type of hub/switch or router, case (panel box), wiring, fusing, banana terminals, power switch, and laptop (for displaying web site).

All the aforementioned devices and components are equipped altogether and programmed as required to do its tasks and displayed as shown in **Figure 17.**

5. CONCLUSION

In this paper, a novel, low-cost, and flexible home control and monitoring system using web technologies and Android smartphones has been proposed and built. The proposed model utilized some web services and protocols for data delivery and reception. Android smartphone with Wi-Fi support can be depended for accessing and controlling home environment after setting up the app. The hardware controller used is a PLC with some needed accessories to satisfy a generalized home or industrial control system. This generalized system has been limited (but not restricted) to temperature measurement of home as a case study to prove its operation. The control algorithm adopted has been limited (but not restricted) to three types of control: Manual, Two-step, and PID algorithms. Of course one can add other algorithms such as fuzzy control if the case study is more complex than temperature measurement. The system proved a good mixture of industrial-wise devices such as: PLC, analog units, sensor, actuator, heater, fan, HMI screen, etc. with internet and network technologies such as: servers, Ethernet interfaces, web sites, Android app, LAN network, some important protocols and IP, IoT, etc. The work contained the hardware design of the required electronic circuits and building the overall system besides the high level by hand programming. For work extension or using some alternatives, 3G or 4G networks can be adopted to connect with the system. Another development depends on using a wireless network inside home to satisfy wireless communication between the gateway and the home devices using Xbee or other wireless technologies. Also, implementation of voice commands for controlling the devices and appliances by speech can be developed.

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Figure 1: The overall architecture of the proposed system

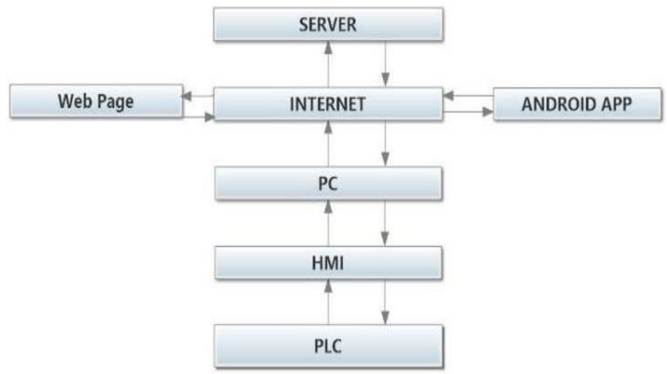

Figure 2: Connection diagram of the PLC to the Internet

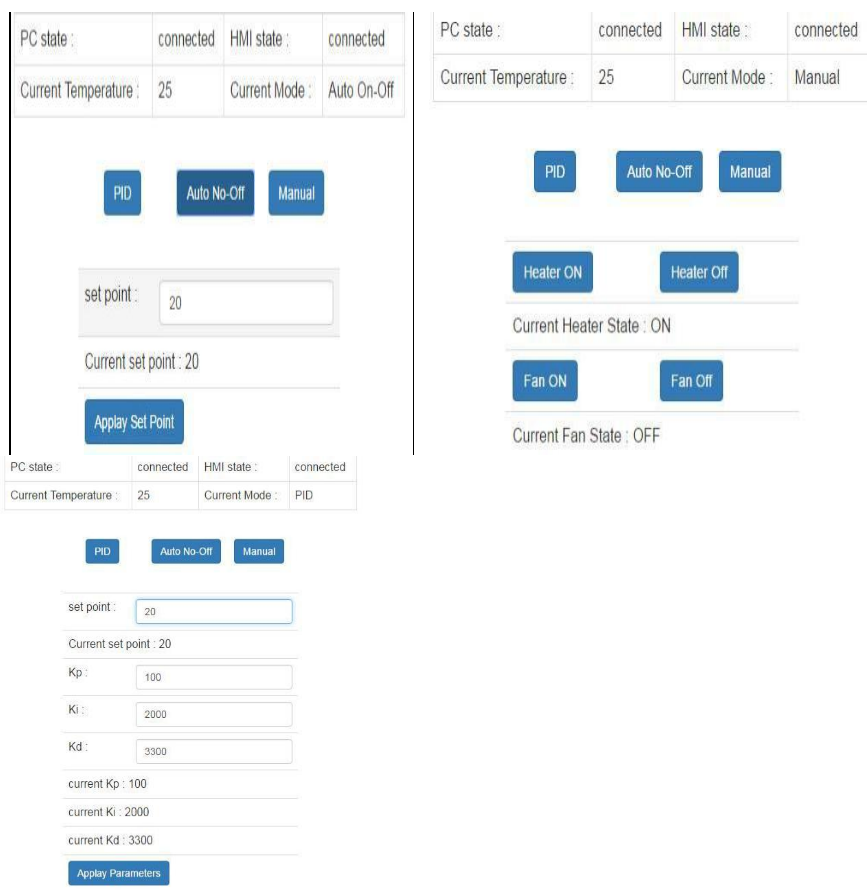

Figure 3: Different interfaces of the designed web site

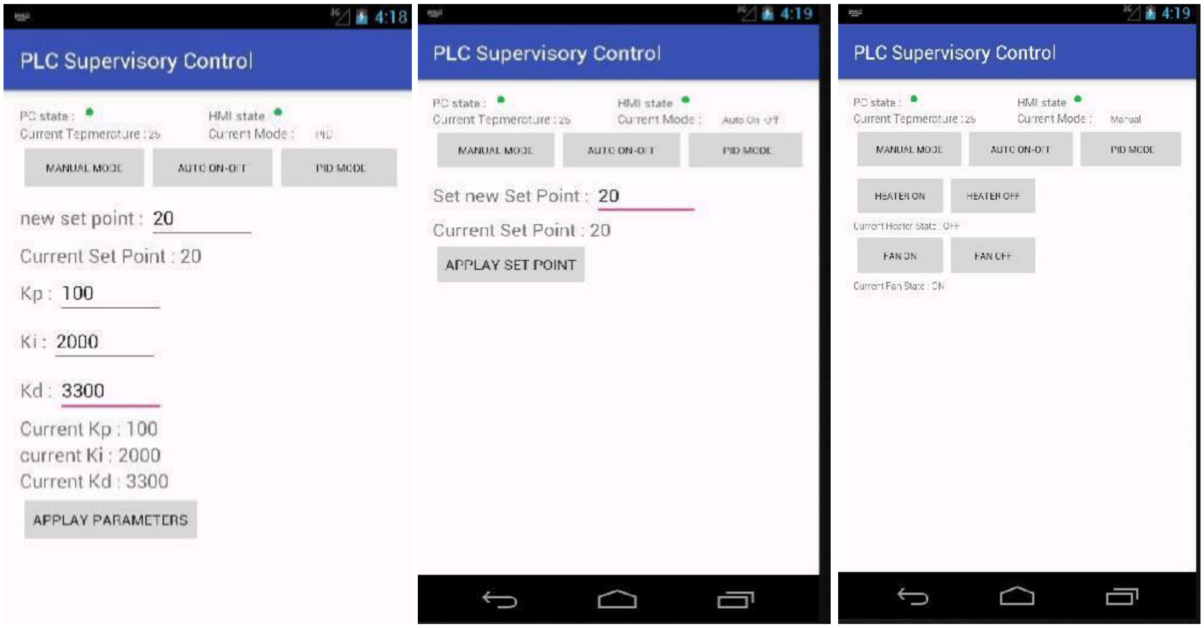

Figure 4: Different interfaces of the Android app

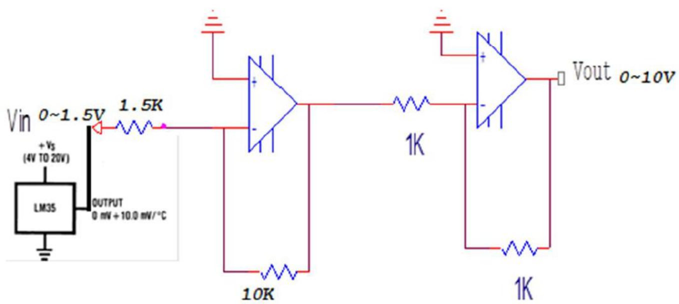

Figure 5: LM35 connection to signal conditioner Circuit

Fig.6: PLC controller (Schneider Electric)

Fig. 7: Analog I/O extension module

Fig.8: Ethernet communication module

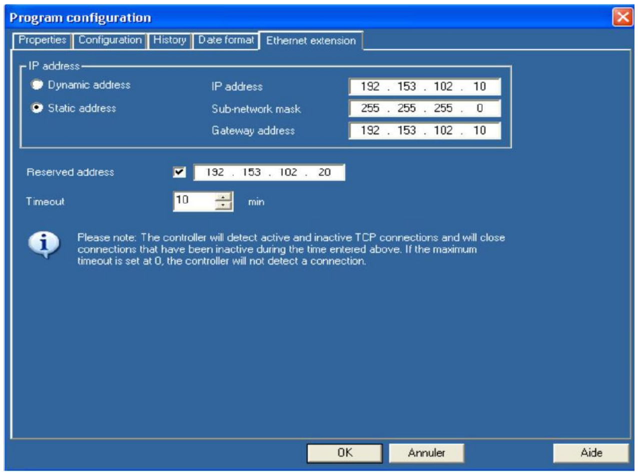

Fig.9 IP setting of Ethernet module

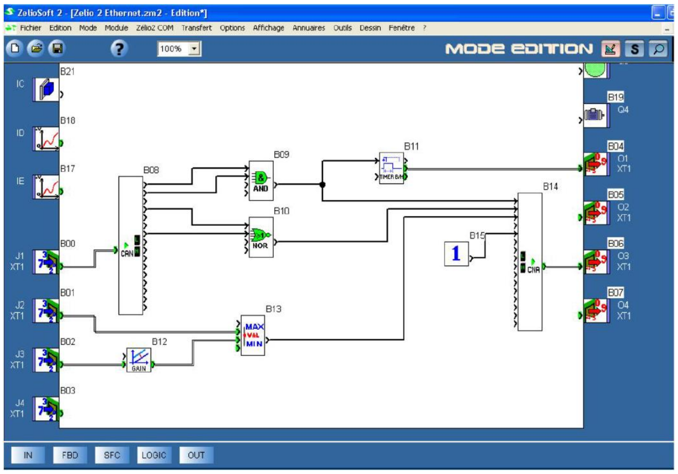

Fig. 10: The four I/O words accessible by the Ethernet communication module

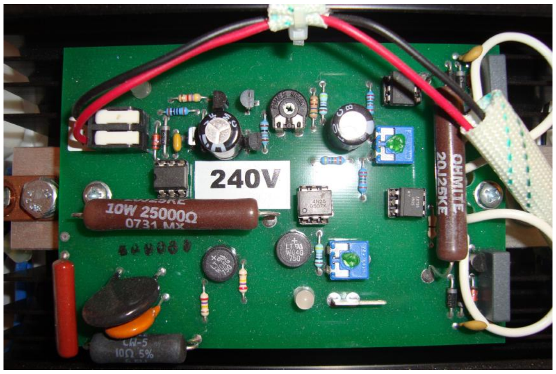

Fig. 11: A real photo for the SCR power controller (actuator)

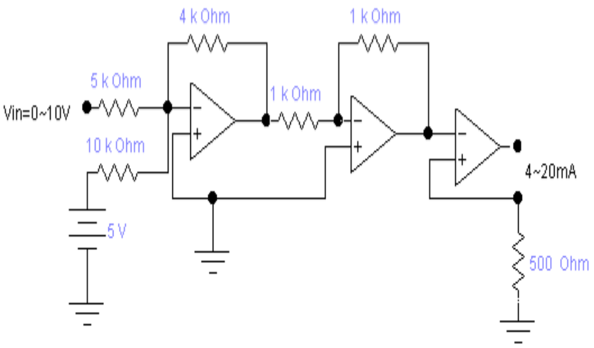

Fig. 12: Signal conditioner circuit that supplies the SCR with the required current signal

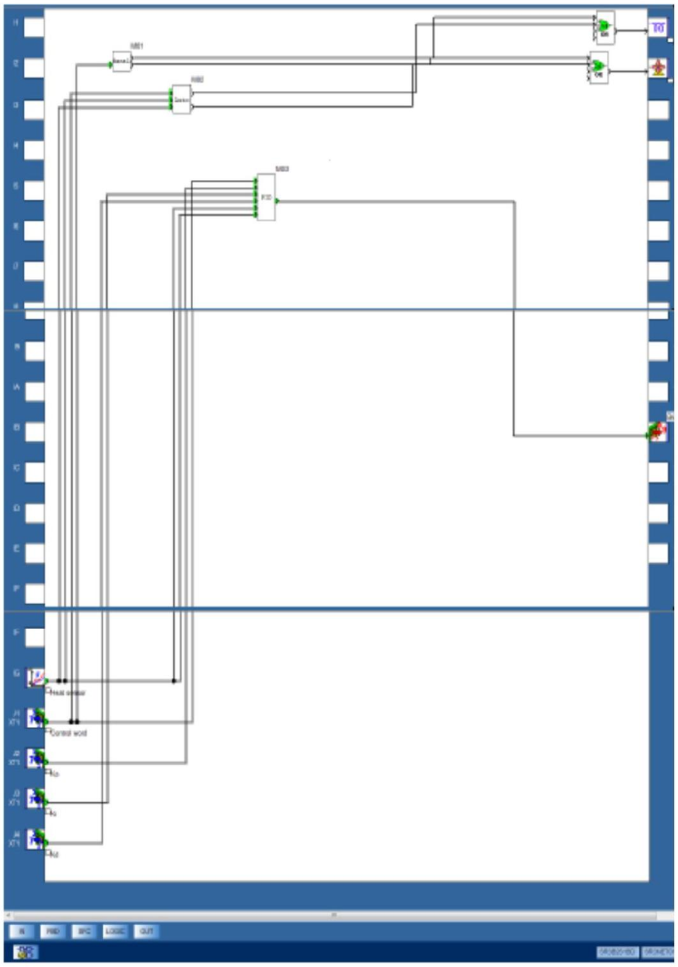

Fig. 13: The PID controller

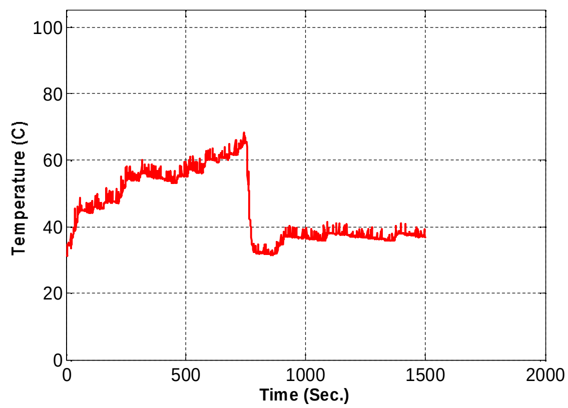

Fig.14: The real-time response of the PID temperature control system for two set points: 65°C and 40°C

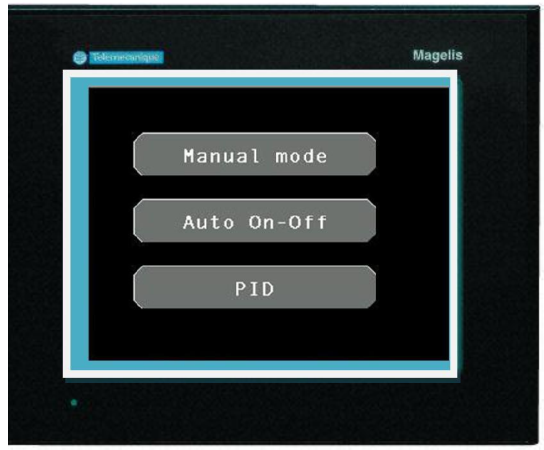

Fig. 15: The Designed HMI

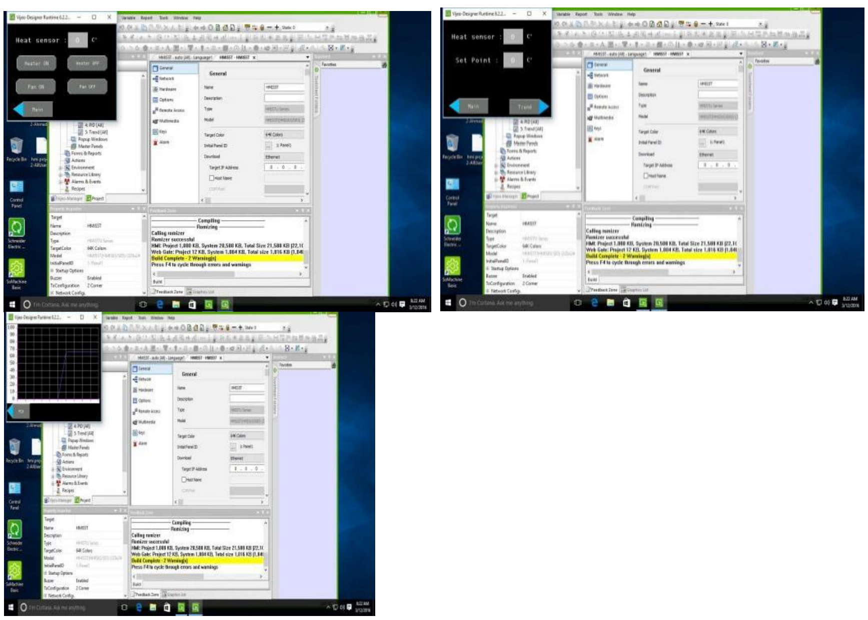

Fig. 16: Three-of-Five screens of the HMI designed for local control

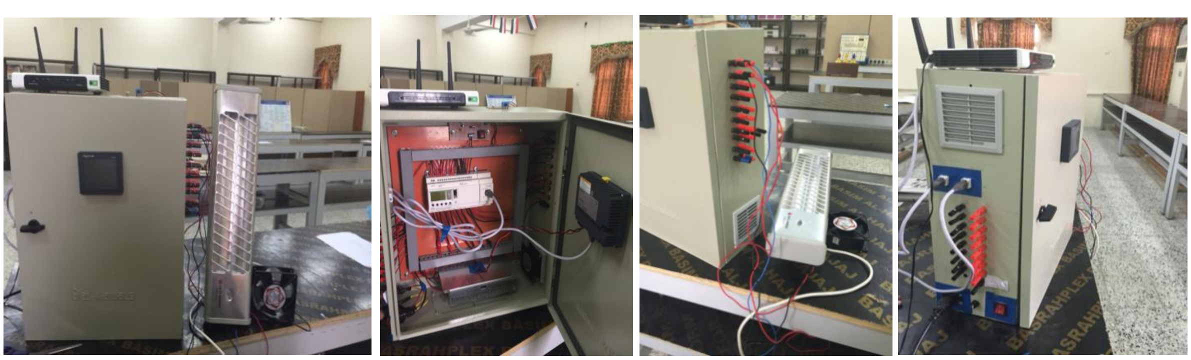

Fig. 17: The overall designed web- and Android-based PLC home temperature control system