DESIGN AND IMPLEMENTATION OF A RELIABLE AND SECURE CONTROLLER FOR SMART HOME APPLICATIONS BASED ON PLC

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Abstract

Programmable logic controllers (PLCs) are increasingly being used to realize modern safety-critical instrumentation and control (I&C) applications. Examples of these applications are industrial automation and control systems, plant process safety protection systems, and digital I&C systems embedded in nuclear power plants (NPPs) that require high levels of performance, reliability, and flexibility. PLC technology serves as the nervous system of the I&C application and bridge between the operators and the executed critical runtime functions. This paper proposes a PLC-based home security controller based on the ladder logic programming model. The design, analysis, and hardware implementation of this controller are presented. The designed system consists of three basic modules which are a sensing module used for reading the data of the input field devices, a computation-based decisional module used for executing the programming model, and an actuating module used for sending the control commands to the output field devices. This designed system is implemented on the Allen-Bradley CompactLogix PLC controller and Human Machine Interface (HMI) panel programmed as the graphical user interface. The experimental simulation results of the real hardware connection demonstrate that the proposed system is reliable, safe, and feasible for smart home security applications.

1. INFORMATION

Instrumentation and control systems (I&Cs) are heterogenous and complex integrated devices composed of a diverse set of embedded computer-based systems [1], [2], [3]. These embedded systems include hardware components, programming software models, cabling, power supplies and communication networks that are tightly integrated in such a way that allow interaction between the operator and the plant [4], [5], [6]. Examples of the safety-critical applications for these types of systems are industrial automation-based control devices, smart manufacturing, automotive and transportation systems, and healthcare cyber-

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physical systems (CPSs) (see Fig. 1) [4], [7], [8], [9]. To ensure the safety of the public and the environment, and prevent a catastrophe before taking an action, all of these I&C applications must operate reliably and generate output signals in a predictable, reliable, and safe behavior especially in environments where hazardous conditions may occur [4], [10].

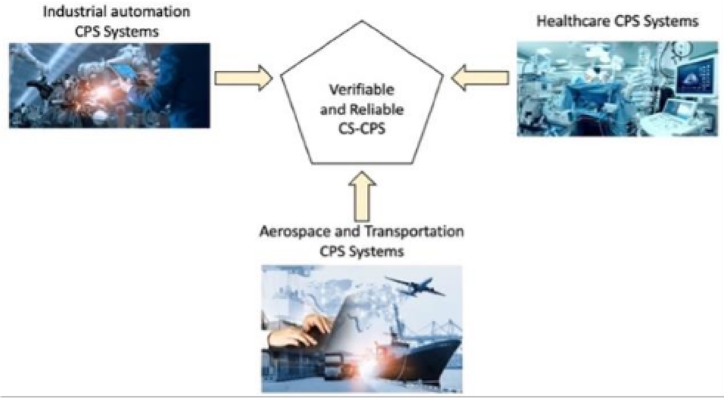

Fig. 1. The applications of safety-critical instrumentation and control systems, [4], [7].

PLCs and field programmable gate arrays (FPGAs) have gained popularity as software-based digital control platforms in the last two decades [11], [12]. They have been used in the realization of complex tasks embedding arithmetic, logic, and comparison functions of the safety and security I&C application [13], [14], [15], [16]. Additionally, PLC programmable device uses the standard IEC 61508 with its functional safety to control systematic and hardware failures [17]. PLCs are typically programmed using one of the specific programming languages defined by the International Electrotechnical Commission standard IEC 6113. The standard specifies the semantics of two textual programming languages which are structured text (ST) and instruction list (IL), and the syntax of three graphical programming languages which are ladder diagram (LD), function block diagram (FBD), and sequential function chart (SFC) [18], [19]. These programming languages can be used to realize different set of computer-based digital applications and perform combinational-based Boolean logic and bit-shift operations (AND, OR, XOR, SR, Inverter gate, etc.), and decoding, encoding and multiplexing circuits [20], [17]. Furthermore, these programming languages are used in the implementation of sequential logic devices as D-type flip-flop (D-FF) used in shift registers [21], counters timers, proportional integral derivative (PID) controllers, and supervisory control and data acquisition (SCADA) systems [5], [22], [23], [24], [25], [26], [27].

Basically, a PLC consists of a simple architecture built based on a microprocessor hardware architecture that reads the input data values through sensing units at the beginning of a scan cycle, performs the required computation based on the decision logic, and writes the output commands through actuating units [28], [29]. The scan cycle typically consumes time which depends on the size of the programming model written by the designer and the manufacturing technology of the PLC device [18], [30].

Several researchers have focused on this research field. In [31], a new PLC design was proposed based on FPGA technology with parallel execution. They have converted the ladder diagram programming language to equivalent very high-speed integrated circuit hardware description language programs (VHDL) using two steps. The first step was converting the LD program to a VHDL code by a state machine process. The second step was optimizing the state machine process to assure independent operations can be executed in parallel.

The design prototype implementation of a PLC by means of an FPGA was presented in ref. [32]. All the arithmetic and logic operations were implemented fully in hardware using VHDL programming models. In [33], hardware architecture inspired by biological processes and fault tolerance techniques was developed to achieve high levels of resiliency and automation in industry. This architecture was aimed to use the programmable design in next generation nuclear power plants (NPPs) digital applications. Jee et al. [34] described a new formal verification technique for functional block diagram used in industrial PLC programming. The FBD model was translated into a Verilog coding model that has been checked against errors and different failure modes.

Kim et al. [35] presented an integrated system that can verify the correct operation of process automation systems developed using IEC 61131-3 through 3D simulations. The PLC controller communicated with external simulator in real time to exchange and to verify the program. Economakos etc al. [36] proposed a design environment that utilizes program-based and model-based for the development of PLC applications. The presented tool flow was used in the design of new digital control algorithms with offering performance improvements compared to software capabilities. Alemzadeh et al. [37] presented an approach for assessment the safety of robotic telesurgical systems using system theory and software-based fault injection. Open-source robotic surgical platform was used as a hazard analysis technique. Food and drug administration database were used to demonstrate the feasibility of the proposed approach for safety-based design of robotic tele surgical systems.

The main contribution of the current paper is designing a safe home security system using PLC technology. In addition, the field input and output digital devices are designed by using the concept of state transition diagram in building the programming ladder diagram as decision module. The real experiments are carried out and the performance of the proposed controller is investigated.

The rest of this paper is organized as follows. Section 2 presents the design and implementation of the hardware-based abstract model for the proposed home security system. Section 3 describes the operation of the ladder logic programming model of the designed system. In section 4, the experimental work and its results are discussed. Section 5 summarizes the main important points of this paper and gives some future works.

2. THE PROPOSED RELIABLE CONTROLLER DESIGN

This section describes the design of the proposed PLC-based home security system, as shown in Fig. 2 and Fig. 3. The proposed system is designed and implemented using the Allen-Bradley CompactLogix PLC controller hardware, Human Machine Interface (HMI) panel and Rockwell Automation Studio 5000 software. Ladder logic diagram (LLD) programming language is used to control the operation of the home security application consisting of three sensors, a locking mechanism, and a control user interface.

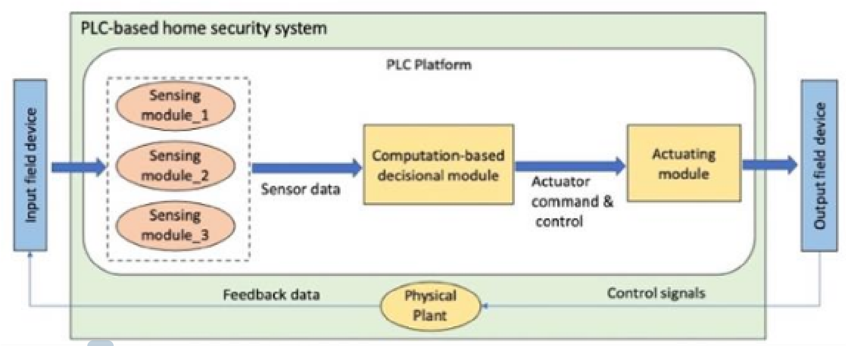

Fig. 2. The abstract model for the proposed home security system.

2.1. Hardware

The proposed security system, as shown in Fig. 3, consists of three basic modules: sensing, computation-based decisional, and actuating. The system includes a laser photoelectric sensor, a motion or proximity sensor, a limit switch, a siren speaker, HMI panel, two mushroom two-position push-pull switches, two momentary push button switches, and three lights (red, yellow, and green) inside the light tower. This design provides a visual picture of how power flow occurs and how the HMI panel is interacted with the PLC system using the same tags that are created in the studio 5000 software. The ladder logic program includes twelve rungs connected in parallel between two power rails.

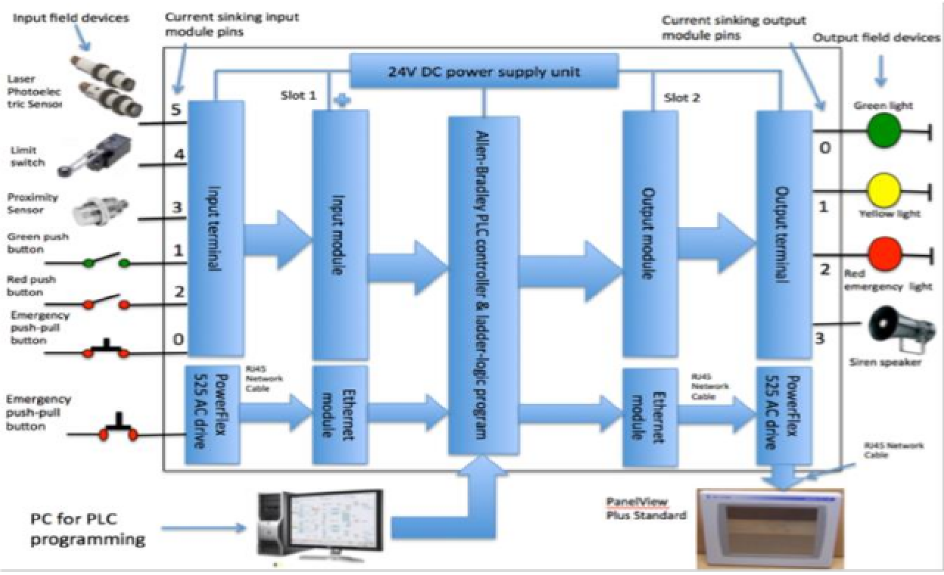

Fig. 3. Block diagram of the hardware modules for PLC and field device interface for the proposed home security system.

2.2. Software

A PLC ladder logic program is executed repeatedly as long as the processor is in the run mode, in which the processor reads the status of the input values through the input modules and stores these values in an area of the memory called the input image table. The processor is then run from the first instruction on the first rung to evaluate the conditions of the input instructions and update the status of the output image table to control the action of the actuators through the output modules and the Ethernet modules, as presented in Fig. 3.

The process of evaluating the input image table and updating the output image table takes few milliseconds depending on the scan time of the PLC device. In addition, the design process of the PLC controller using the ladder logic diagram requires from the control engineer to understand the application requirements and specifications. For example, PLC input rung instructions must be selected using a process that looks at the input field device contact type Normal Open (NO) or Normal Close (NC) and its operational condition (activated or not activated). Ultimately, the input rung instruction selected, XIC or XIO, is affected by the requirement for the output field device to be either on or off. Furthermore, the operation of the reliable system is modeled in a state diagram using six different states, as presented in Fig. 4 and TABLE I. The operation is described according to the following specifications:

1) When the system is powered on, the system is rendered inactive or in the OFF state. The OFF state can be engaged at any time by pressing the "SYSTEM OFF" button on the HMI panel. Note, when the system is off, a message will appear displaying that the system is in fact OFF.

2) If the "SYSTEM ON" button is pressed, the system is rendered ON thus, allowing sensors and system functionality to proceed. A message will appear, displaying that the system is ON.

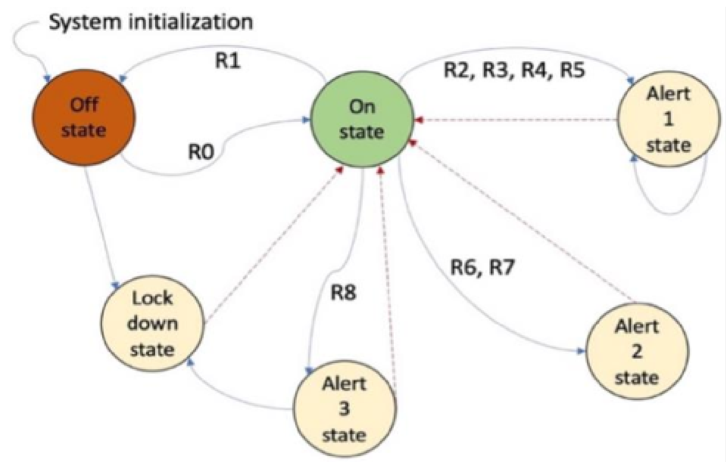

Fig. 4. The state transition diagram that describes the operation of the reliable controller.

Tab. 1. The states that describe the operational model of the reliable controller for the home security system.

State	Description
OFF	When the "SYSTEM OFF" button is pressed on the HMI panel, a message "SYSTEM OFF" will appear
ON	Allowing sensors and system functionality to proceed by pressing the "SYSTEM RESET" button
Alert_1	When there is a movement on the porch, system alert the homeowner with a message "PERSON ON PORCH" displayed on HNI panel AND the green light of the tower is turned on
Alert_2	When the limit switch is tripped, a message "DOOR IS BREACHED" is displayed AND the yellow light of the tower is turned on
Alert_3	When the through beam photoelectric sensor is tripped, a flashing message "INTRUDED IN HOUSE" will appear AND a siren will sound in case of the control panel is out of sight
Lockdown	If the "LOCKDOWN" button is pressed, this state locks the designated safe room automatically

3) When the system is ON and there is movement on the porch, the system will alert the homeowner with a message displayed on the HMI panel stating, "PERSON ON PORCH." The background of the indicator is green, which matches the green light in the light tower. This state is known as the ALERT 1 state. Note, the sensor must be active for at least 5 seconds before notifying the homeowner. Additionally, the sensor is checked 10 seconds after engaging the ALERT 1 state. If the sensor is still active after 10 seconds, the ALERT 1 state remains true. If the sensor is inactive after 10 seconds, the state returns to false.

4) When the limit switch is tripped once, the ALERT 2 state becomes true. The ALERT 2 state consists of displaying the message: "DOOR IS BREACHED" on the HMI panel. The background of the display is yellow, which matches the yellow light turned on in the light tower.

5) When the through beam photoelectric sensor is tripped, the alert 3 state is engaged causing the highest alert for the homeowner. A flashing message will appear on the HMI panel, which states: "INTRUDED IN HOUSE". Furthermore, a siren will sound notifying the homeowner in case the control panel is out of sight.

6) If the ALERT 3 state is active, the lockdown state will also become active. This state locks the master bedroom or designated safe room automatically. Additionally, if the "LOCKDOWN" button is pressed by the user on the HMI panel, the system will enter the lockdown state.

7) The only way to reset the system while keeping the system ON is by pressing the "SYSTEM RESET" button.

3. THE OPERATION OF SYSTEM SOFTWARE

This section describes the operation of the ladder logic programming model of the designed system to produce the required control for implementing the state diagram of home security system. The ladder logic program is divided into four parts as discussed in the following subsections.

3.1. Part1: ON state & OFF state

The first two rungs of the ladder logic are designed to implement the first state (ON state) and the second state (OFF state) of the controller state diagram, as shown in Fig. 5. Rung 0 has three input instructions type (XIC) and one input instruction type (XIO). The (XIC) input instructions are connected as OR logic using a branch and used to evaluate the condition of the "SYSTEM ON" button on the HMI panel, the "SYSTEM_ON" state, which is used as a sealing instruction, and the green button. In addition, this rung has one output instructions type (OTE) used to activate the "SYSTEM_ON" Boolean expression that enables the sensing process of the security system to be started. Rung 1 has three input instructions type (XIC) and one input instruction type (XIO). These three (XIC) inputs instructions are connected as an OR logic using a branch and used to evaluate the conditions of the "SYSTEM OFF" button on the HMI panel, the "SYSTEM_OFF" state, which is used as a sealing instruction, and the red button. Furthermore, this rung has one output instructions type (OTE) used to activate the "SYSTEM_OFF" Boolean expression that stops the functionality of the system.

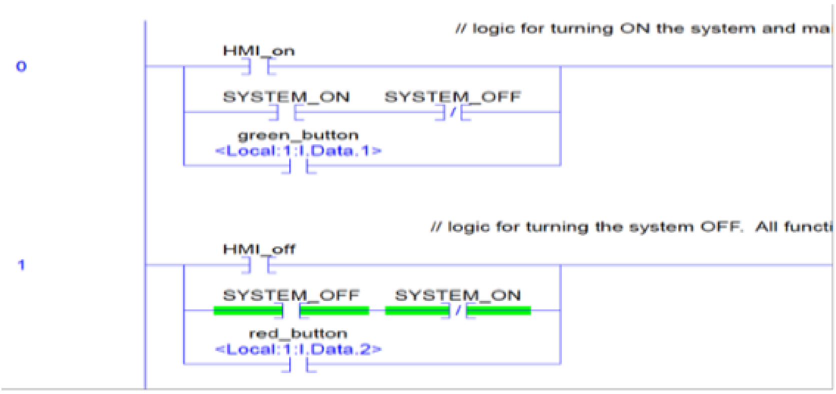

Fig. 5. The first part of ladder logic program for the PLC and field device interface for the controller of the home security system.

3.2. Part2: proximity sensor, timer, ALERT1

Three rungs are designed to control the operation of the porch sensor, as presented in Fig. 6. Rung 2 of the ladder logic, senses any movement on the porch using two input instructions type (XIO) connected as AND logic and used to evaluate the condition of the proximity sensor and the "SYSTEM OFF" button. In addition, rung 2 and rung 3 include two timers that are designed as logic to control the operation of alert1. The first timer, which is "timer" timer, as shown on rung 2, is used to start accumulating for five seconds whenever the proximity sensor is activated. On rung 3, the second timer, which is "thirtysec_tim" timer, starts timing for ten second as soon as the first timer completes its timing process and activates the "Done" bit signal. On this rung, four input instructions type (XIO) and one input instruction type (XIC) are used as AND logic to evaluate the conditions of the five alert states: ALERT1, ALERT2, ALERT3, ALERT1_STAYON, and RESET. These five input instructions are connected as OR logic with the "timer. DN" bit signal.

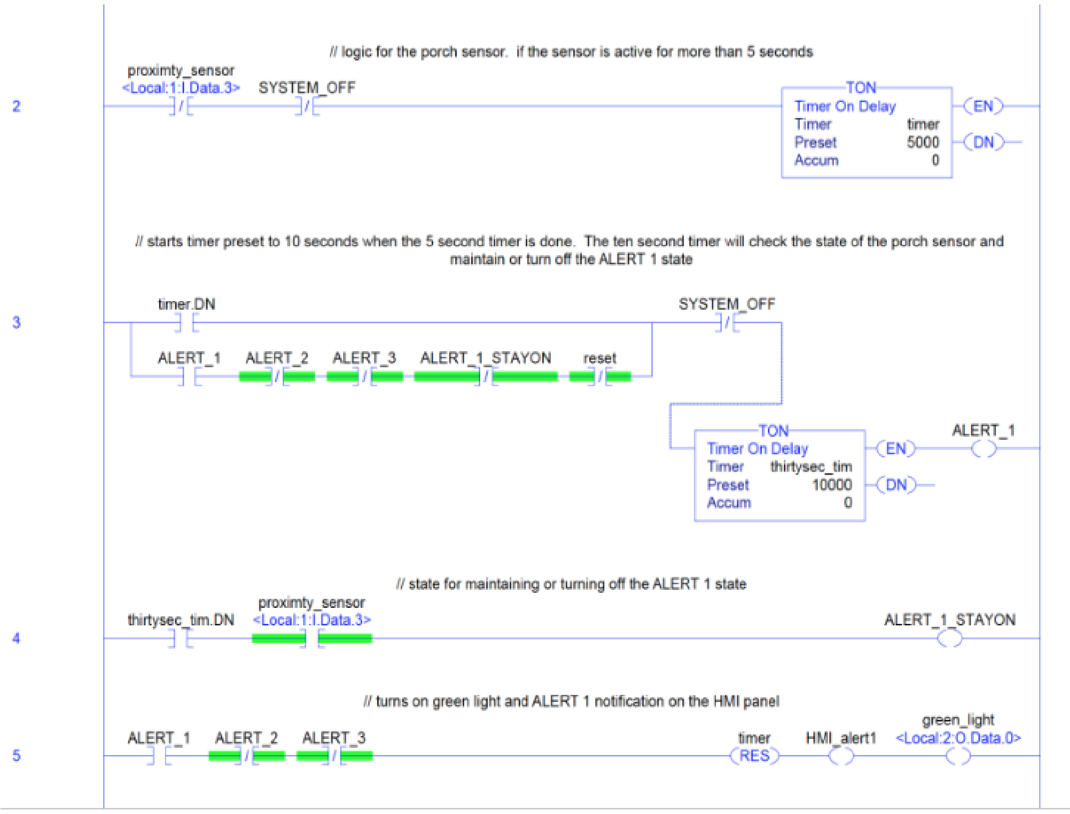

Fig. 6. The second part of ladder logic program for the PLC and field device interface for the controller of the home security system.

The fifth rung, which is rung 4, includes two input instructions type (XIC) connected as AND logic and one output instruction type (OTE). This rung is used for maintaining or turning off the ALERT1 state. Whenever the "thirtysec" timer completes its timing process for ten seconds activates its "Done" bit signal, and the proximity sensor is still tripped for more than five seconds, the ALERT1 state stays on. The sixth rung, which is rung 5, includes two input instructions type (XIO) and one input instruction type (XIC) connected as AND logic to evaluate the conditions of the three alert states: ALERT1, ALERT2, and ALERT3. Also, this rung contains three output instructions type (OTE) to reset the "timer" timer on rung 2, activate the ALERT1 notification on the HMI panel, and turn the green light on.

3.3. Part3: ALERT2

Two rungs are used to implement the ALERT2 state, as shown in Fig. 7. The first rung, which is rung 6, includes six input instructions: two of them are type (XIC) used to evaluate the condition of the limit switch and the ALERT2 state and four of them are type (XIO) used to evaluate the condition of ALERT1, ALERT2, ALERT3, RESET, and SYSTEM_OFF states. If the limit switch is tripped simulating the case study (door breached), the ALERT2 state is activated. As long as the ALERT2 state is true, the ALERT2 notification on the HMI panel is activated, and the yellow light becomes on as shown on rung 7 which includes three input instructions and two output instructions.

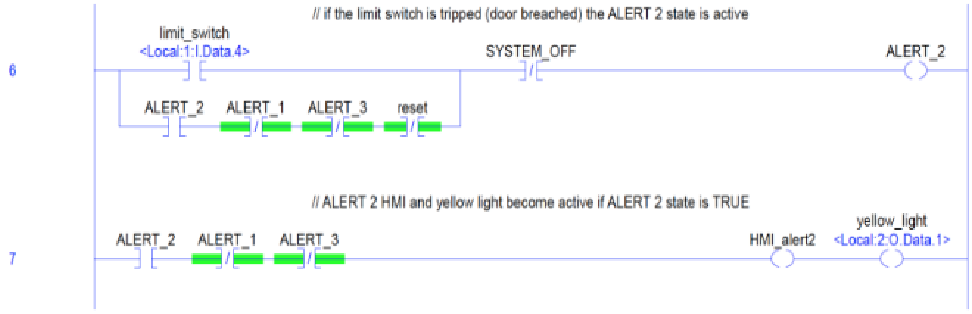

Fig. 7. The third part of ladder logic program for the PLC and field device interface for the controller of the home security system.

3.4. Part4: ALERT3 & RESET

Finally, four rungs are used to implement the ALERT3 and RESET states as shown in Fig. 8. The first rung, rung 8, includes four input instructions: two of them are type (XIC) used to evaluate the condition of the laser photoelectric sensor and the ALERT3 state and two of them are type (XIO) used to evaluate the condition of RESET, and SYSTEM_OFF states. If the hallway beam laser sensor is tripped simulating the case study (intruder in house), the ALERT3 state is active. As long as the ALERT3 state is true, a master bedroom door automatically locks, the ALERT3 notification on the HMI panel is activated, a speaker outputs a loud siren, and the yellow light becomes on as shown on rung 9 and rung 10. Rung 9 has three input instructions type (XIC) connected as OR logic and used to evaluate the conditions of the “HMI_LOCKDOWN_ALERT” state as a sealing instruction, ALER3 state, and the “LOCKDOWN” button on the HMI panel. Rung 11 includes one input instruction type (XIC), used to evaluate the condition of the “RESET SYSTEM” button on the HMI panel, and one output instruction type (OTE), used to reset the entire system. During any of the ALERT states and LOCKDOWN state, if the “RESET SYSTEM” button is pressed, the entire system will be reset and then transition to the safe and reliable state.

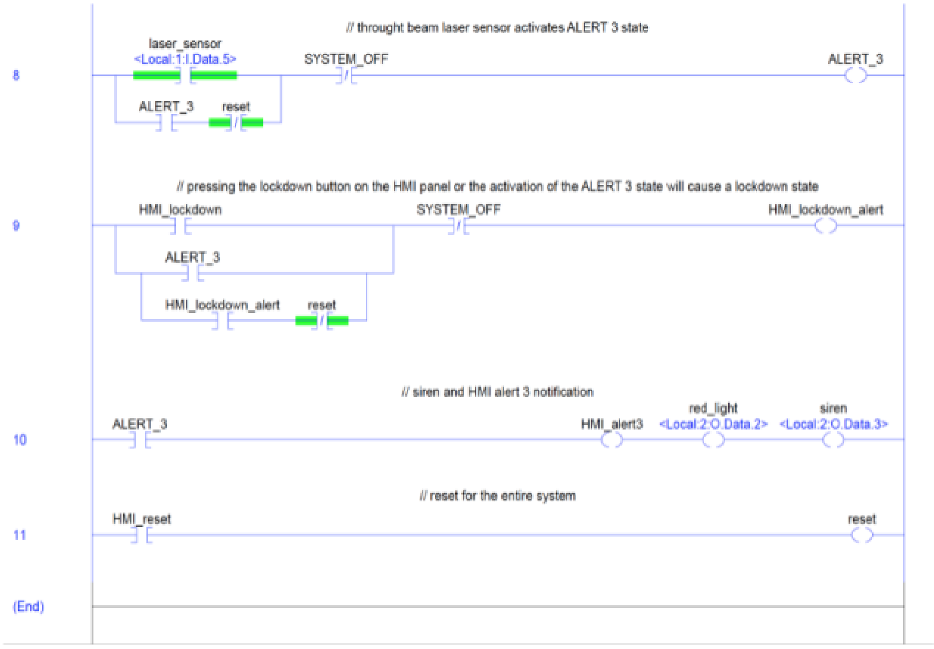

Fig. 8. The fourth part of ladder logic program for the PLC and field device interface for the controller of the home security system.

4. EXPERIMENTAL WORK

This section presents the real experimental work that is carried out. A schematic hardware layout is presented in Fig. 9 in which the input and output field devices are connected in the research laboratory to the I/O modules and the Ethernet module of the Allen-Bradley CompactLogix PLC controller through a set of terminal modules. The green push button switch is connected as a normally open (NO) connection to the input terminal module, where the green button goes to input 1, the red button goes to input 2, and the emergency push-pull button goes to input 0. Furthermore, the input module is connected as current sourcing module, so the 24V DC power supply, which is turned off by using a circuit breaker, is connected to the common terminal of this module. The emergency push-pull button switch is connected as a normally close (NC) connection to the input terminal module. In addition, the green light of the light-tower is connected to output 0 of the output terminal module, the yellow light is connected to output 1, and the red emergency light is connected to output 2. The output terminal module itself is not supplying 24V DC so the positive 24V DC has been connected to the terminal module.

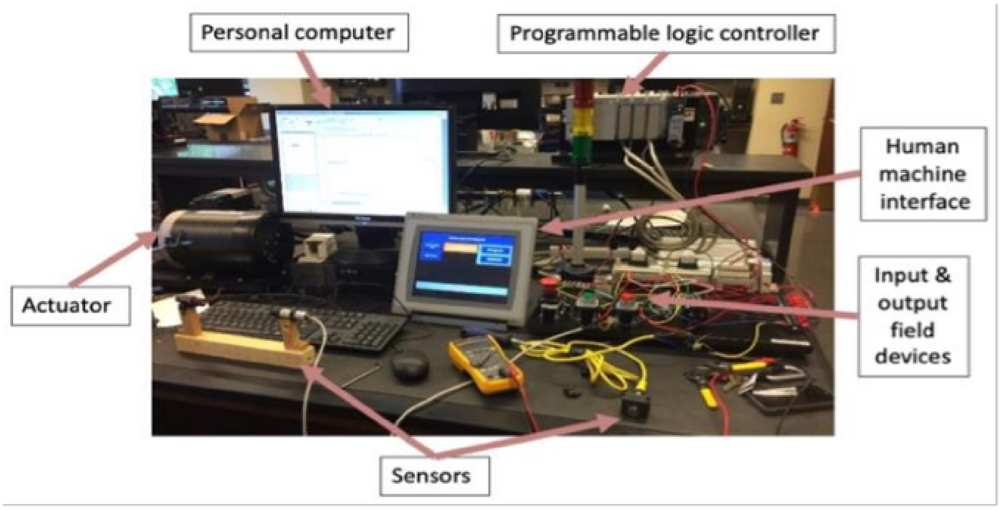

Fig. 9. The real hardware connection of PLC and field device interface for the home security system.

The ladder logic program is downloaded to the PLC memory through the USB 3.0 Gigabit Ethernet adapter. The processor is putted in Run mode to continue running read input status, solve the control program and turn output registers ON/OFF, and update outputs.

The Graphical User Interface (GUI) of the proposed design including eleven global objects is presented in Fig. 10. The proposed design uses the “SYSTEM ON” object to start the functionality and activate the sensing process of the home security system. The “SYSTEM OFF” object is used to stop the functionality of the designed system and disable the sensing process.

The executed experiments prove that the proposed designed system is reliable and feasible for home security applications.

Fig. 10. Human Machine Interface (HMI) Panel including the proposed design.

5. CONCLUSION AND FUTUTRE WORK

In this paper, we develop and implement a PLC-based home security system. The state of the diagram-based controller is presented using the ladder programming model. In addition, the robust and deterministic operation of the proposed system is discussed and analyzed. The design process of these types of embedded systems gives the I&C control engineers and operators of the physical plant the ability to deal with different applications in real time. Also, using these different modules such as analog and digital modules for input and output applications enable the engineer to connect the PLC to different types of sensors and actuators.

Future work can focus on various topical areas, including analyzing the dependability and security levels of the PLC-based controller using Markov chains and fault trees. Furthermore, the formal methods can be used to verify the correct operation of the runtime programming model. In final, we could attempt to make the designed system operate against any potential permanent failure mode by proposing a hybrid fault-tolerant mechanism for the decision model of the state diagram-based controller.

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Conflicts of Interest

The authors state that there is no conflict of interest.

REFERENCES

1. W. Rahmaniar and A. Hernawan, "Real-Time Human Detection Using Deep Learning on Embedded Platforms: A Review," *Journal of Robotics and Control (JRC)*, vol. 2, no. 6, pp. 462–468, 2021.
2. A. R. Al Tahtawi, M. Agni, and T. D. Hendrawati, "Small-scale Robot Arm Design with Pick and Place Mission Based on Inverse Kinematics," *Journal of Robotics and Control (JRC)*, vol. 2, no. 6, pp. 469–475, Nov. 2021.
3. A. W. L. Yao and H. C. Chen, "An Intelligent Color Image Recognition and Mobile Control System for Robotic Arm," International Journal of Robotics and Control Systems, vol. 2, no. 1, pp. 97–104, Feb. 2022.
4. N. R. Storey, *Safety Critical Computer Systems*. Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 1996.
5. J. A. Rehg and G. J. Sartori, *Programmable Logic Controllers*, 2 edition. Upper Saddle River, N.J: Pearson, 2008.
6. J. Yoo, J.-H. Lee, and J.-S. Lee, "A research on seamless platform change of reactor protection system from PLC to FPGA," *Nucl. Eng. Technol.*, vol. 45, no. 4, pp. 477–488, Aug. 2013, doi: 10.5516/NET.04.2012.078.
7. J.-Y. Chen, K.-C. Tai, and G.-C. Chen, "Application of Programmable Logic Controller to Build-up an Intelligent Industry 4.0 Platform," *Procedia CIRP*, vol. 63, pp. 150–155, Jan. 2017, doi: 10.1016/j.procir.2017.03.116.
8. J. Knight, *Fundamentals of dependable computing for software engineers*. Boca Raton: CRC Press, 2012.

9. M. P. Heimdahl, L. Duan, A. Murugesan, and S. Rayadurgam, “Modeling and requirements on the physical side of cyber-physical systems,” in *Twin Peaks of Requirements and Architecture (TwinPeaks), 2013 2nd International Workshop on the*, 2013, pp. 1–7. Accessed: Mar. 31, 2017. [Online]. Available: http://ieeexplore.ieee.org/abstract/document/6614716/

10. “Introduction to Embedded Systems, Second Edition | The MIT Press.” https://mitpress.mit.edu/books/introduction-embedded-systems-second-edition (accessed Apr. 19, 2022).

11. “Recommended Approaches and Design Criteria for Application of Field Programmable Gate Arrays in Nuclear Power Plant Instrumentation and Control Systems - 1022983.” EPRI, 2011.

12. H. Hendra, P. S, H. Hernadewita, H. Hermiyetti, and Y. Yoserizal, “Applying Programmable Logic Control (PLC) for Control Motors, Blower and Heater in the Rubber Drying Processing,” *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 7, no. 1, p. 131, Apr. 2021.

13. M. Pawlenka and J. Škuta, “Use of PLC and PIC for realization of intelligent family house,” in *Proceedings of the 2015 16th International Carpathian Control Conference (ICCC)*, May 2015, pp. 374–378. doi: 10.1109/CarpathianCC.2015.7145107.

14. J. Heo, C. S. Hong, S. H. Ju, Y. H. Lim, B. S. Lee, and D. H. Hyun, “A Security Mechanism for Automation Control in PLC-based Networks,” in *2007 IEEE International Symposium on Power Line Communications and Its Applications*, Mar. 2007, pp. 466–470. doi: 10.1109/ISPLC.2007.371169.

15. A. Andrashov, V. Kharchenko, V. Sklyar, L. Reva, V. Dovgopolyi, and V. Golovir, “Verification of FPGA electronic designs for nuclear reactor trip systems: test-and invariant-based methods,” in *Design & Test Symposium (EWDTS), 2010 East-West*, 2010, pp. 92–97. Accessed: Aug. 26, 2015. [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5742120

16. M. M. Patil, S. Subbaraman, and P. S. Nilkund, “IEC control specification to HDL synthesis: Considerations for implementing PLC on FPGA and scope for research,” in *2010 International Conference on Control Automation and Systems (ICCAS)*, Oct. 2010, pp. 2170–2174.

17. R. Girardey, M. Hübner, and J. Becker, “Safety aware place and route for on-chip redundancy in safety critical applications,” in *VLSI (ISVLSI), 2010 IEEE Computer Society Annual Symposium on*, 2010, pp. 74–79. [Online]. Available: http://ieeexplore.ieee.org/abstract/document/5571804/

18. S. Ichikawa, M. Akinaka, H. Hata, R. Ikeda, and H. Yamamoto, “An FPGA implementation of hard-wired sequence control system based on PLC software,” *IEEJ Trans. Electr. Electron. Eng.*, vol. 6, no. 4, pp. 367–375, Jul. 2011, doi: 10.1002/tee.20670.

19. P. Gsellmann, M. Melik-Merkumians, A. Zoitl, and G. Schitter, “A Novel Approach for Integrating IEC 61131-3 Engineering and Execution into IEC 61499,” *IEEE Trans. Ind. Inform.*, pp. 1–1, 2020, doi: 10.1109/TII.2020.3033330.

20. R. Chakrabarty, S. Roy, T. Pathak, and N. Kumar Mandal, “Design of Area Efficient Single Bit Comparator Circuit using Quantum dot Cellular Automata and its Digital Logic Gates Realization,” *Int. J. Eng.*, vol. 34, no. 12, pp. 2672–2678, Dec. 2021, doi: 10.5829/ije.2021.34.12c.13.

21. H. Alamdar, G. Ardeshir, and M. Gholami, “Using Universal Nand-nor-inverter Gate to Design D-latch and D Flip-flop in Quantum-dot Cellular Automata Nanotechnology,” *Int. J. Eng.*, vol. 34, no. 7, pp. 1710–1717, Jul. 2021, doi: 10.5829/ije.2021.34.07a.15.

22. S. Khairullah, “Toward Biologically-Inspired Self-Healing, Resilient Architectures for Digital Instrumentation and Control Systems and Embedded Devices,” *Theses Diss.*, Jan. 2018, [Online]. Available: https://scholarscompass.vcu.edu/etd/5671

23. S. S. Khairullah and C. R. Elks, “Self-repairing hardware architecture for safety-critical cyber-physical-systems,” *IET Cyber-Phys. Syst. Theory Appl.*, vol. 5, no. 1, pp. 92–99, 2020, doi: https://doi.org/10.1049/iet-cps.2019.0022.

24. L. Pang, C.-W. Wang, M. Lawford, and A. Wassyng, “Formal verification of function blocks applied to IEC 61131-3,” *Sci. Comput. Program.*, vol. 113, pp. 149–190, Dec. 2015, doi: 10.1016/j.scico.2015.10.005.

25. P. Chodorowski and M. Chmiel, “IEC 61131-3 compliant PLC structure based on FPGA multi-core solution,” in *2016 International Conference on Signals and Electronic Systems (ICSES)*, Sep. 2016, pp. 237–242. doi: 10.1109/ICSES.2016.7593858.

26. A. Setiawan and A. Ma’arif, “Stirring System Design for Automatic Coffee Maker Using OMRON PLC and PID Control,” International Journal of Robotics and Control Systems, vol. 1, no. 3, pp. 390–401, Oct. 2021.

27. W. Sapto Aji and A. Junaidi, "Sistem Pengontrol Suhu Ruangan dengan Algoritma PID Menggunakan PLC Omron CP1e-NA20DR-A," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 3, no. 2, pp. 47–55, Dec. 2017.
28. Y. Yuliza, R. Muwardi, D. W. Pratama, M. H. Santoso, and M. Yunita, "Modification of Control Oil Feeding with PLC Using Simulation Visual Basic and Neural Network Analysis," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 8, no. 1, pp. 38–50, Apr. 2022.
29. R. D. Puriyanto, S. A. Akbar, and A. Aktawan, "Desain Sistem Biodiesel Berbasis Plc Berdasarkan Diagram Keadaan," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 4, no. 2, pp. 100–109, 2018.
30. F. N. kassab bashi, S. S. Khairullah, and C. R. Elks, "Realization of Dependable Digital Systems for Safety-Critical Computer Systems using FPGAs," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1152, no. 1, p. 012020, May 2021, doi: 10.1088/1757-899X/1152/1/012020.
31. D. Du, Y. Liu, X. Guo, K. Yamazaki, and M. Fujishima, "Study on LD-VHDL conversion for FPGA-based PLC implementation," *Int. J. Adv. Manuf. Technol.*, vol. 40, no. 11–12, pp. 1181–1190, Feb. 2009, doi: 10.1007/s00170-008-1426-4.
32. M. Chmiel, R. Czerwinski, and P. Smolarek, "IEC 61131-3-based PLC Implemented by means of FPGA," *IFAC-Pap.*, vol. 48, no. 4, pp. 374–379, 2015, doi: http://dx.doi.org/10.1016/j.ifacol.2015.07.063.
33. S. S. Khairullah and C. R. Elks, "A Bio-Inspired, Self-Healing, Resilient Architecture for Digital Instrumentation and Control Systems and Embedded Devices," *Nucl. Technol.*, vol. 202, no. 2–3, pp. 141–152, Jun. 2018, doi: 10.1080/00295450.2018.1450014.
34. E. Jee *et al.*, "FBDVerifier: interactive and visual analysis of counter-example in formal verification of function block diagram," *J. Res. Pract. Inf. Technol.*, vol. 42, no. 3, p. 171, 2010.
35. Y. Kim, S.-y Lee, and S. Lim, "Implementation of PLC controller connected Gazebo-ROS to support IEC 61131-3," in *2020 25th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*, Sep. 2020, vol. 1, pp. 1195–1198. doi: 10.1109/ETFA46521.2020.9212096.
36. C. Economakos, M. Skarpetis, and G. Economakos, "Program-based and model-based PLC design environment for multicore FPGA architectures," in *2014 11th International Conference on Informatics in Control, Automation and Robotics (ICINCO)*, Sep. 2014, vol. 01, pp. 726–733.
37. H. Alemzadeh *et al.*, "Systems-Theoretic Safety Assessment of Robotic Telesurgical Systems," in *Computer Safety, Reliability, and Security*, vol. 9337, F. Koornneef and C. van Gulijk, Eds. Cham: Springer International Publishing, 2015, pp. 213–227. doi: 10.1007/978-3-319-24255-2_16.

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