Journal of Networking Technology

DLINE JOURNALS

Print ISSN: 0976-898X
Online ISSN: 0976-8998

JNT 2025: 16 (4)
https://doi.org/10.6025/jnt/2025/16/4/163-171

Optimizing Agricultural Harvesting with a PLC-Based Robotic Arm

Zenan Xiong[1], Guojun Hong[2]
[1]College of Physical Education, Changsha University
Changsha, Hunan. China

[2]National Engineering Research Centre of Dredging
Shanghai. China
Xiongwei932022@126.com

ABSTRACT

This paper presents an electrical control system for a harvesting robotic arm that integrates Programmable Logic Controller (PLC) technology with the Particle Swarm Optimization (PSO) algorithm. Aimed at addressing labor shortages and enhancing harvesting efficiency in modern agriculture, the system uses PLC for reliable, real time control of the robotic arm's movements. At the same time, PSO optimizes the harvesting sequence to minimize travel distance and positioning errors. The control architecture includes sensor inputs (X1–X4) and electromagnetic valve outputs (Y1–Y4), with image processing for fruit recognition and localization. Experimental results demonstrate that the PSO enhanced system significantly improves harvesting accuracy, reduces errors especially under challenging conditions like intense light and increases overall operational efficiency. The approach enables precise, adaptive fruit picking while preserving produce quality, showcasing the potential of intelligent algorithms combined with industrial automation in agricultural robotics. This synergy offers a scalable solution for sustainable, high efficiency harvesting in diverse crop environments.

Keywords: Harvesting Robotic Arm, Electrical Control System, Programmable Logic Controller (PLC), Particle Swarm Optimization (PSO), Fruit Recognition, Trajectory Optimization, Agricultural Automation

Received: 18 May 2025, Revised 30 August 2025, Accepted 4 September 2025

1. Introduction

Due to the ongoing rise in global population, a pressing issue we face is how to meet the growing demand for food resources. Consequently, contemporary agriculture is evolving towards a more effective and sustainable approach by implementing state of the art technologies, including crop protection, seed identification, moisture control, and environmental observation, while integrating them with intelligent systems created by today's engineers. The introduction of "smart robots," which can possess visual, auditory, olfactory, or other cognitive abilities similar to those of humans, enables these automated robots to understand their environment more effectively and respond quickly to changes [1]. The widespread use of such technology in the industrial sector not only yields considerable economic benefits but also fosters positive societal impacts [2]. As science and technology progress, the agriculture and biotechnology sectors confront unprecedented challenges, including entities that are susceptible, adaptable, prone to damage, requiring proper management, diverse, and recognized as living, thus necessitating artificial intelligence to exhibit traits that surpass traditional intelligence. With advancements in technology, the utilization of robotic arms is becoming increasingly common. They can withstand extreme weather conditions, such as high temperatures, corrosion, and toxicity, while demonstrating exceptional precision in manipulation. Their operational behavior is not solely reliant on sensors but is also enhanced by PLC technology, making their functioning more straightforward and effective. Employing robotic arms for harvesting tasks can significantly lessen human labor intensity and complete the entire operation within 20 hours. The utilization of this technology offers immense advantages to modern agriculture, particularly in regions facing labor shortages [3].

2. Related Work

A robotic arm is a sophisticated mechanical assembly designed to accomplish specific functions through interconnected joints and linkages. Its form is reminiscent of a human hand, yet its operational principles differ. It can transfer an object from one fixed point to another, facilitating the proximity of objects. It not only aids in tasks but also provides stable support for items. With the emergence of the 1980s, industrial robotic arm technology saw substantial advancements, with the Stanford/JPL three-finger hand I and the Utah/MIT four-finger hand [4] serving as benchmarks. The deployment of these technologies has become increasingly prevalent, especially the Stanford/JPL three-finger hand, which introduced a modular design for fingers with nine adjustable degrees of freedom [5]. The superiority of the Stanford/JPL hand extends beyond a singular mechanical arm; its distinctive modular architecture allows it to possess multiple joints and degrees of freedom, integrating position, touch, force, and other related data for an accurate understanding of the surrounding environment, resulting in revolutionary changes in human intelligence. Since the late 1980s, numerous academic institutions have focused on the development of multi-functional massage devices, with the Beijing University of Aeronautics and Astronautics (BUAA) and the Harbin Institute of Technology (HIT) being particularly noteworthy. BUAA developed the first three-finger massage device, followed by the BUAA-II.. The BUAA-III Orchid Finger massage devices stand out, while HIT differentiates itself with innovative solutions that offer users globally more convenient choices for massage equipment and enhanced comfort during their massage sessions. Zhang S et al. created the HIT/DLR multi-finger hand [6]. The 5DOF robotic arm for tomato harvesting is regarded as a trailblazer among agricultural robots. It features a distinctive design with a spatial open-chain mechanism, granting significant flexibility in capturing and gathering various crop types, particularly those that necessitate precise control. As the number of links increases, the robot's size also enlarges, especially when dealing with the picking, sorting, and transportation of crops like watermelons and cantaloupes, which are bulkier than human capability. The robot's construction must account for its load-bearing capacity. Nations such as Japan and the United States have a relatively high farmer population. However, as agriculture evolves toward larger-scale, diverse, and precise methods, labor shortages have become increasingly evident [7]. Numerous tasks, including the harvesting and transport of fruits and vegetables, as well as grafting, require significant technology and skilled labor. These tasks often present considerable challenges due to their specific nature. In light of this situation, several developing nations are actively channeling investments into agricultural robotics. Their initiatives have yielded remarkable benefits.

To achieve success, it is essential to not only build upon and refine existing robotic arms but also to optimize them to improve their self regulation abilities. With technological advancements, a novel four finger robot has been created with exceptional self regulation features. This robot can adapt its gripping force based on different environments, making it easier to accomplish picking tasks. Furthermore, through simulations and numerical analysis, we have conducted comprehensive studies on the elastic deformation of fruit trees and pertinent control algorithms to ensure theoretical reliability. Japanese agricultural machinery incorporates cutting edge sensing technology, allowing for precise regulation of plant growth and swift insertion and transplantation. For instance, the planting insertion machine can rapidly place plants measuring several millimeters in length, achieving a very high insertion speed. Additionally, these machines are outfitted with four adequately wide cylinders that facilitate a broad range of transportation. By implementing human robot collaborative robots, these machines can autonomously search, pinpoint, and direct operations, efficiently completing various tasks through their own control systems, including motion trajectory planning, joint manipulation, and end effector activities. Collaborations among research institutions have led to the creation of robots equipped with sophisticated servo vision systems, greatly enhancing the productivity of rural areas [8]. Moreover, the “MAGAU” robot, developed by the PeDene and Motte research institutes, and the “CITRUS” robot from the Jasa research institute, offer more effective mechanical solutions for agricultural products, allowing for more precise execution of tasks related to agriculture [9]. The partnership between the National Vegetable and Tea Research Institute and Gifu University has resulted in a new robot designed for harvesting eggplants, cabbages, and melons.

The Zhu X research team conducted further investigations and successfully created a new machine for harvesting melons [10]. Once the fruits are collected, the release mechanism must be capable of allowing them to fall naturally from the harvested items. This release process typically involves cutting and pulling. However, when conditions allow, pulling is preferred to maintain the visual quality and texture of the harvested items and to inhibit bacterial growth. For instance, it is crucial to keep fruits like peaches, plums, and apricots undamaged. Nevertheless, due to the unique structure of certain fruits, employing traditional cutting methods can pose difficulties, particularly when dealing with thinner stems. Thus, one of the obstacles for farmers is effectively utilizing harvesting robotic arms to safeguard the quality of their produce. Currently, agricultural harvesting technologies, both domestically and internationally, face numerous challenges, with a particular focus on improving their efficiency.

Recent research has focused on developing electrical control systems for harvesting robotic arms using PLC technology and optimization algorithms. Roshanianfard et al. [11] (2019) designed a 4 degrees of freedom articulated robotic arm for heavy weight crop harvesting, implementing a PLC-based control unit that achieved an overall average accuracy of 1.85 mm and repeatability of ±0.51 mm. Wang [12] (2025) enhanced hydraulic robotic arm stability by integrating PLC technology with an improved particle swarm optimisation-fuzzy PID (IPSO-FPID) algorithm, demonstrating superior performance with response times of 0.36s and 0.33s for joints 1 and 2, respectively. Roshanianfard & Noguchi [13] (2020) developed a five-fingered end effector controlled by a PLC system using Denavit Hartenberg methodology, achieving 79% harvesting success rate for pumpkins. Wu et al. [14] (2024) proposed integrating RBFNN and PSO algorithms for precision trajectory control, improving tracking accuracy in complex agricultural environments. These studies collectively demonstrate the effectiveness of combining PLC technology with particle swarm optimization for enhanced harvesting robot performance.

3. Mechanical Arm Electrical Control System Technology

3.1 PLC-Based Mechanical Arm Electrical Control System

The introduction of PLC systems has established them as an ideal tool for industrial applications, thanks to their high counting capacity, compact design, and user friendly operation, making them the favored option in various industrial production and research environments [15, 16]. Moreover, advancements in communication capabilities have further improved the functionality of PLC systems. A typical PLC control system comprises four essential components: the CPU, registers, power supply, and input/output interfaces. The CPU handles complex operations, gathering data from its surroundings and translating it into actionable commands, thereby facilitating effective collaboration among different components. The CPU is equipped with a robust self-diagnostic mechanism that can quickly detect any irregularities. It also possesses substantial computational power, allowing it to read and write programs, adhere to various established technical methods, and transmit control instructions to the CPU in a scanning manner, executing corresponding tasks in each cycle. The memory of a PLC has characteristics similar to that of a computer's memory; it not only retains diverse information but also logic variables and programs [17, 18]. Its memory architecture includes system memory for storing various system data, while user memory is designated for client operations, ensuring complete separation between the two. Through sensors, input and output components can monitor and adjust the electronic devices in the vicinity.

3.2 Optimization of Harvesting Mechanical Arm Electrical Control System Based on Particle Swarm Algorithm

When harvesting, robotic arms gather a significant quantity of fruits, and the sequence of their operations greatly influences their efficiency. To tackle this challenge, we can implement intelligent algorithms to enhance the control system, enabling it to perform harvesting tasks more effectively [19]. The particle swarm algorithm can identify the optimal solution from random particles and progressively refine precision, not just within the algorithm itself but also across the entire group.

If we partition a D-dimensional search space into *N iv* sets of particles, where the i^{th} particle represents a D-dimensional vector, then

$$X_i = \left(x_{i1}, x_{i2}, \cdots, x_{iD}\right) \quad (i = 1, 2, \cdots, N) \qquad (1)$$

The motion mode of the i-th particle can be represented by a D-dimensional equation, namely

$$V_i = \left(v_{i1}, v_{i2}, \cdots, v_{iD}\right) \quad (i = 1, 2, \cdots 3) \qquad (2)$$

This formula consists of three different components: the first component describes the motion model of an object; The second component describes the actual situation of the object; The third component describes the direction in which an object moves in relation to other objects, that is, the process of the object moving in a more optimal direction. Through practical situations, we can define the values of these three components as *c=c1=c2=D*, where via refers to the velocity of the object, *vi* [*vi1,. vimax*], and max refers to a constant. Adopting a new particle swarm optimization algorithm with carefully designed, the results are as follows:

$$x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \qquad (3)$$

The purpose of Part 1 is to ensure perfect convergence of the entire particle set, while Parts 2 and 3 aim to ensure local optimal solutions. By setting the weight coefficient, we can achieve faster global convergence at higher u values, while at lower w values, we can achieve slower global convergence. According to our research, when w is within the range of [0.8, 1.2], the convergence of the algorithm improves. However, when w exceeds w>1.2, it is difficult for the algorithm to achieve perfect global convergence. After multiple iterations, we can obtain the local or global optima of the particle swarm. This method is applied to the harvesting sequence of harvesting robots, which enables them to complete harvesting tasks more efficiently and is more conducive to the quality of the harvest. Please refer to Figure 1 for the specific operation method.

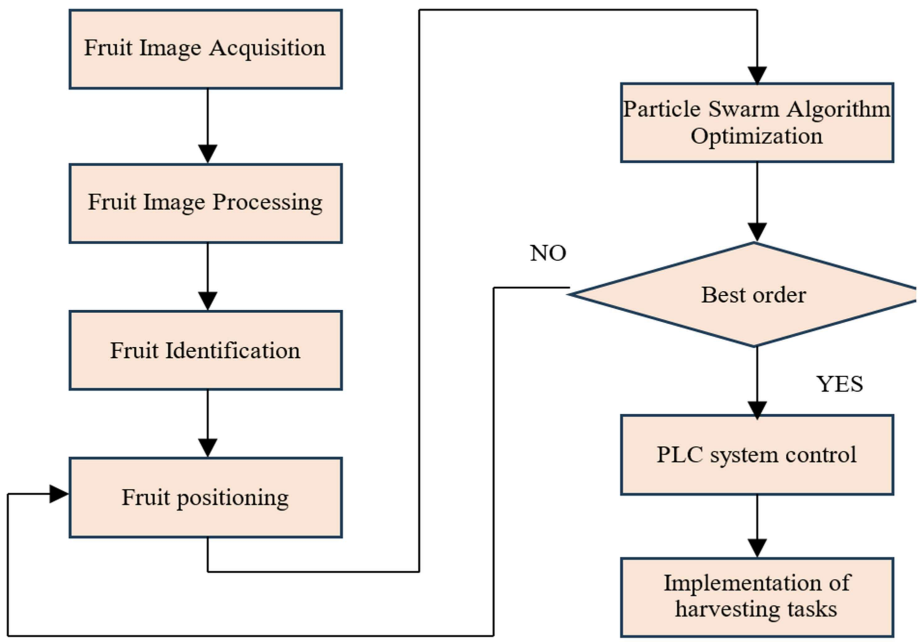

Figure 1. shows a control process implemented using particle swarm and PLC technology

When using a robot to harvest fruits, it first collects and analyzes information about the surrounding environment and then operates using PLC. If a larger quantity of fruits needs to be harvested, it will utilize the particle swarm algorithm to optimize the harvesting process, obtaining a more efficient harvesting scheme. In this way, the harvesting tasks can be completed quickly and accurately based on the predefined harvesting process.

4. Experimental Design and Results Analysis

4.1 PLC Electrical Control System Experiment for Harvesting Robot

Through the application of the particle swarm algorithm, we validated the effectiveness of the PLC control system. Based on simulated actual working conditions, we constructed a basic framework for a harvesting mechanical arm, equipping it with various manipulative functions, including up and down, left and right, rotation, and others. Through programmed control, the robot can execute multiple control functions, enabling it to interpret control signals sent from sensors and computers, as well as perform graphic processing based on the particle swarm algorithm. This enables the robot's control system to perform automatic manipulation efficiently, thereby enhancing the accuracy and efficiency of harvesting. During the experiment, the PLC control system served as the foundation for the mechanical arm's operations, setting various PLC control commands for sensors, switches, and other devices. The control commands were divided into two parts: input commands and output instructions. During the control of output commands, the control system can interpret input commands, perform manipulation in conjunction with the computer, and optimize the output command instructions. The PLC electrical control system's input-output mainly includes various sensor inputs, electromagnetic valve controls, and switch controls. The input stage focuses on collecting sensor positions, primarily comprising four groups of control commands (*X1*-*X4*). The output stage includes various electromagnetic valve control commands, mainly consisting of four groups of control commands (*Y1*-*Y4*). The control system utilizes computer image processing to identify and locate fruit images. It employs the particle swarm algorithm to determine the harvesting sequence, which is then transmitted to the PLC control system to complete the harvesting tasks.

4.2 Result Analysis

Through a series of studies, we found that the use of the particle swarm algorithm can significantly reduce harvesting errors. The reason is that it can make more precise adjustments to the fruit's position based on specific algorithms, reducing the mechanical arm's mistakes and allowing for a more stable completion of the harvesting task, thereby greatly improving harvesting efficiency. Figure 2 demonstrates the reliability of this algorithm.

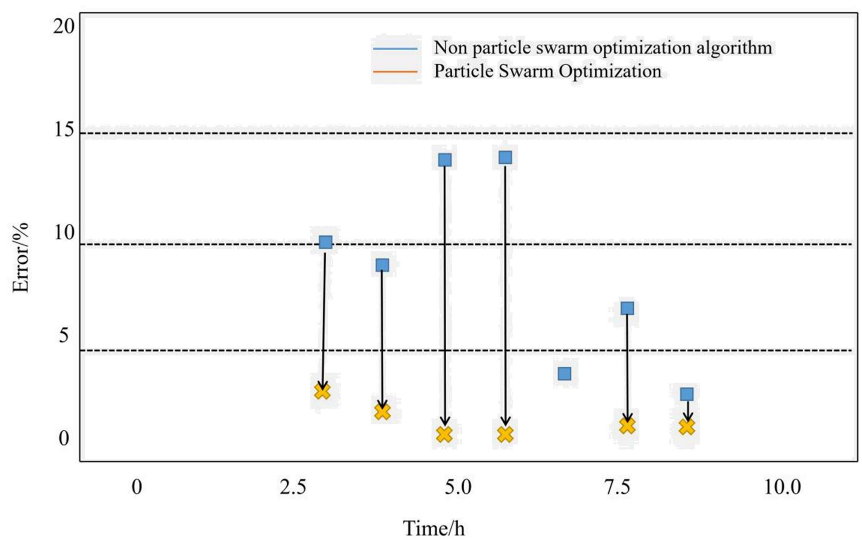

Figure 2. Error Statistics Results

Through investigation, we discovered that when we gather an equal quantity of green peppers, we opt to utilize particle swarm optimization to manage their transportation during the collection phase. Our findings indicate that, compared to not implementing this algorithm, we can reduce the transportation distance during the harvesting process and enhance harvesting efficiency. This observation is illustrated in Figure 2. By employing the particle swarm optimization algorithm, the harvesting robot can schedule the harvesting times more systematically and achieve superior performance within a limited timeframe, significantly boosting work efficiency. The primary objective of this research is to enable the robotic arm to perform high-precision handling tasks. A common error in handling operations occurs when placing the material grabbing action on the I shaped wheel. Therefore, the critical metrics for assessing the robot control system are the success rate and accuracy of material grabbing, where success refers to the ratio of successful grabs to the total attempts. Refer to the work wheel experiment for specific erroneous results illustrated in Figure 3.

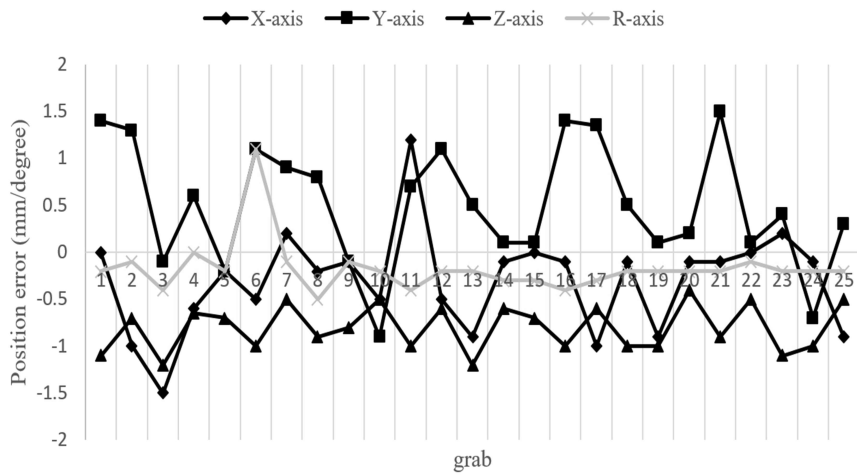

Figure 3. Positioning Error under Strong Light Conditions

The introduction of PLC systems has established them as an ideal tool for industrial applications, thanks to their high counting capacity, compact design, and user friendly operation, making them the favored option in various industrial production and research environments [11,12]. Moreover, advancements in communication capabilities have further improved the functionality of PLC systems. A typical PLC control system comprises four essential components: the CPU, registers, power supply, and input/output interfaces. The CPU handles complex operations, gathering data from its surroundings and translating it into actionable commands, thereby facilitating effective collaboration among different components. The CPU is equipped with a robust self-diagnostic mechanism that can quickly detect any irregularities. It also possesses substantial computational power, allowing it to read and write programs, adhere to various established technical methods, and transmit control instructions to the CPU in a scanning manner, executing corresponding tasks in each cycle. The memory of a PLC has characteristics similar to those of a computer's memory; it not only retains diverse information but also logic variables and programs [17, 18]. Its memory architecture includes system memory for storing various system data, while user memory is designated for client operations, ensuring complete separation between the two. Through sensors, input and output components can monitor and adjust the electronic devices in the vicinity.

5. Conclusion

When harvesting, robotic arms gather a significant quantity of fruits, and the sequence of their operations greatly influences their efficiency. To tackle this challenge, we can implement intelligent algorithms to enhance the control system, enabling it to perform harvesting tasks more effectively [15]. The particle swarm algorithm can identify the optimal solution from random particles and progressively refine precision, not just within the algorithm itself but also across the entire group.

References

[1] Zou, X. (2021). A multi-objective particle swarm optimization for trajectory planning of fruit picking manipulator. *Agronomy*, *11*(29), 129-132.

[2] Su, C. Y. (2021). Continuous control strategy of planar 3-linkage under actuated manipulator based on broad neural network. *Actuators*, *10*(12), 9-11.

[3] Yang, D., Wu, Y., Huo, D. (2021). Research on design of cross-aisles shuttle-based storage/retrieval system based on improved particle swarm optimization. *IEEE Access*, *PP*(99), 1-1.

[4] Zhao, J., Zhu, X., Song, T. (2022). Serial manipulator time-jerk optimal trajectory planning based on hybrid IWOAPSO algorithm. *IEEE Access*, *10*, 10.

[5] Hao, Z., Li, C., Zhang, H., et al. (2022). Control and realization of intelligent fishing system based on PLC and fuzzy PID algorithm. *Journal of Physics: Conference Series*, *2246*(1), 012042.

[6] Zhang, S., Yuan, X., Docherty, P. D., et al. (2021). An improved particle swarm optimization algorithm and its application in solving forward kinematics of a 3-DOF parallel manipulator. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *235*(5), 896-907.

[7] Zhang, S., Yuan, X., Docherty, P. D., et al. (2021). An improved particle swarm optimization algorithm and its application in solving forward kinematics of a 3-DOF parallel manipulator. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *235*(5), 896-907.

[8] Liu, H., Wang, X., Li, M. (2021). External force estimation for robotic manipulator based on particle swarm optimization. *International Journal of Advanced Robotic Systems*, *18*(6), 4507-4512.

[9] Liu, C., Feng, Q., Tang, Z., et al. (2022). Motion planning of the citrus-picking manipulator based on the TO-RRT algorithm. *Agriculture*, *12*, 10-21.

[10] Zhu, X., Li, S., Cheng, H., et al. (2022). Application of particle swarm optimization algorithm in photovoltaic constant pressure water supply electrical control system. *Journal of Physics: Conference Series*, *2203*(1), 012061.

[11] Roshanianfard, A., Noguchi, N., Kamata, T. (2019). Design and performance of a robotic arm for farm use. *International Journal of Agricultural & Biological Engineering*, *12*(1), 146-158.

[12] Wang, J. (2025). Stable control of hydraulic robotic arm during operation using PLC technology. *Automatika: Journal for Control, Measurement, Electronics, Computing and Communications*, *66*(2), 1-9.

[13] Roshanianfard, A., Noguchi, N. (2020). Pumpkin harvesting robotic end-effector. *Computers and Electronics in Agriculture*, *174*, 105503.

[14] Wu, Z., Zhang, Z., Jiang, Y., Du, H. (2024). Precision trajectory control for agricultural harvesting robots: Design and implementation. In *2024 International Conference on Intelligent Computing and Data Mining (ICDM)* (pp. 42-48). Chaozhou, China: IEEE.

[15] Huh, J. H., Otgonchimeg, S., Seo, K. (2016). Advanced metering infrastructure design and test bed

experiment using intelligent agents: Focusing on the PLC network base technology for Smart Grid system. *The Journal of Supercomputing*, *72*, 1862-1877.

[16] Ghiasi, M., Niknam, T., Wang, Z., et al. (2023). A comprehensive review of cyber-attacks and defense mechanisms for improving security in smart grid energy systems: Past, present, and future. *Electric Power Systems Research*, *215*, 108975.

[17] Wang, Z., Zhang, Y., Chen, Y., et al. (2023). A survey on programmable logic controller vulnerabilities, attacks, detections, and forensics. *Processes*, *11*(3), 918.

[18] Bayindir, R., Cetinceviz, Y. (2011). A water pumping control system with a programmable logic controller (PLC) and industrial wireless modules for industrial plants—An experimental setup. *ISA Transactions*, *50*(2), 321-328.

[19] Cai, B., Liu, Y., Liu, Z., et al. (2012). Using Bayesian networks in reliability evaluation for subsea blowout preventer control system. *Reliability Engineering & System Safety*, *108*, 32-41.