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Research Article

Wireless Networked Optimal Controllers for Multiple Plants

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Abstract

The wireless communication technologies nowadays are the most common ubiquitous innovations used in our life. It is much easier to run than wired one, and its applications are increasing steadily. It is now extensively utilized in wireless equipment controlling during the continuous development. That is, from a reasonable distance, we can monitor and control our electronics and electrical equipment. It can be said that tools can only be managed with a controller in hand from a distance without being close to the controller. One of the popular technology requirements in the present time is wireless technology. In this article, the proposed multi plant multi controller (MPMC) system is based on wireless sensor networks (WSNs). The aims are to design and implement of wireless closed-loop optimal control system for multiple plants. The system consists of two main parts: the station part and the sensing part. The station part is designed for the purpose to control the system through the graphical user interface (GUI) designed in the LabVIEW program that gives signals to the sensing part wirelessly through the ZigBee nodes. The sensing part receives a signal from the station part wirelessly through the ZigBee node and used a wireless speed sensor to calculate the speed of connecting DC motors. Then, the sensing part returns the measure reading to the station side through another ZigBee node, to show the result in the GUI controlling the operations of the two plants. The work proves the feasibility of implementing the optimal MPMC systems through wireless networks using ZigBee technology.

Keywords: *WSNs, LabVIEW, ZigBee module, Arduino UNO, multiple plants*

1. Introduction

The MPMC systems are now used widely in many applications in industry, agriculture, defense and health care. The widely used plants are the DC motors utilized by many control systems in the present time. Therefore, the control of the speed and/or position of DC motors plays a very important function in plants. This paper, therefore focuses on monitoring and controlling multiple DC motors speed via wireless closed-loop control system. The explanation for wireless regulation of DC motors speed is to conquer the industry problem like maintaining a strategic distance from damage to machines and staying away from the moderate ascent period and high overshooting (Wen *et al*, 2008).

The Wireless network control system (WNCS) components are (actuators, controllers and sensors) that communicate wirelessly instead of wired network. It is becoming a major infrastructure technology for critical control systems in automotive electrical systems, building administration systems, and electronic systems because of their main advantages in lowering installation and lowering costs, great flexibility, and potentially increased safety (Juang *et al*, 2008).

As mentioned earlier, the main purpose of this project is to design and implement a wireless closed-loop system to control and monitor the speed for multiple DC motors, multiple controllers, using low cost, high performance, and low power WSN platforms. This system helps a consumer to control the speed of electric appliances automatically, manually, and remotely using a personal computer PC. Moreover, the consumer can shut down the devices when they reach a specified speed (Nagaraj *et al*, 2010).

In (Chauhan *et al*, 2013) providing the DC motor with wireless speed control for efficient use in industrial applications. The unit consists of a transmitter that produces control signals, wirelessly transmitted to the receiver. The receiver controls the speed of the DC motor provided by the pulse width modulation according to the control signals. With the ZigBee wireless radio frequency module, control signals are transmitted wirelessly. Therefore, to make the system sustainable, the DC motor speed can be controlled wirelessly from the control room.

In (Yang *et al*, 2017) a multi-input multi-output (MIMO) wireless power transfer activated magnetic resonant coupling devices, various 4 transmitters are utilized to improve the quality of simultaneous power transfer to different receivers by constructively

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integrating their induced magnetic fields, a process called magnetic beam forming.

In (Mobasshir Mahbub, 2019) a control unit is designed with Arduino Uno module and the module of the nRF24L01 wireless transceiver, which controls multiple plants. It can be utilized for a variety of purposes such as control for servo motor, light control, DC motor controlling in a multi-purpose radio-controlled vehicle, quadcopter, etc. because it is a multi-purpose radio control. The controller consists of both a transmitter unit and a receiver unit that is assembled with nRF24L01 and Arduino Uno R3. The receiver unit controls the attached equipment according to the transmitter position.

For the optimal control strategies, the particle swarm optimization (PSO) algorithm is considered as one of the promising optimization techniques in many fields due to its low computational cost, ease of implementation and efficient performance. The algorithm has been applied successfully to a lot of applications. Several studies have been explained the use of PSO in PID controllers. Some of those are briefly explained as follows:(Zamani *et al*. 2009) have employed the PSO algorithm to carry out the design of fractional order PID; whose derivative and integral orders are fractional numbers rather than integers; to an automatic voltage regulator. (Mukherjee & Ghoshal, 2007) have used the PSO algorithm to find the optimal PID gains for a thermal power plant. They also compared both craziness based PSO and binary coded genetic algorithms tuning method.

The problem of PID controller tuning satisfying multiple H_∞ performance criteria is also considered. (Kao *et al*, 2006) have presented a design method for the self-tuning PID control in a slider- crank mechanism system by applying PSO algorithm. For the best of our knowledge the PSO method is not used previously to optimize the parameters of the PID controllers of the multiple plant systems.

The rest of this paper is arranged as follows. Description of optimal control strategy and mathematical model are given in section *II* with traditional tuning methods. The proposed MPMC is investigated in section *III*. System implementations are introduced in sections *IV* while simulation results are presented in *V*. The paper is concluded in section *VI*.

2. Optimal controller

The optimal controllers now utilize the artificial techniques of soft computing and traditional ones such as PID types.

2.1 PID Controller Overview

The best set of the PID controller parameters must ensure an efficient performance of the closed loop control system. The parameters are adjustable and it can be changed according to the process. If the process operating points are changed, then the parameters must be changed to new values and this needs a skilled operator to get an efficient performance (Willjuice *et al*, 2009).

The tuning of the PID controller is done by adjusting the gains of Kp, Ki, and Kd. The required performance specifications such as stability margins, dynamic response for both transient and steady state are incurred by the best set of parameters. There are many criteria that can be used to find the best response of the control system. These criteria can be summarized (Wang *et al*, 2008). The Integral of time multiplied by absolute of error (ITAE) where *e(t)* is the error signal and it can be given by.

$$ITAE = \int t|e(t)|dt \tag{1}$$

2.2 PSO Algorithm

In this algorithm, particles fly around a multi-dimensional search space for adjusting its previous state and the state of its neighbors. The aim is to search the solution space by swarming the individual towards the best fitting solution. Fitness function is specified for each solution to find the performance of each particle. The idea of modification of a searching for solution by using PSO is illustrated in Fig. 1(Ebrahim *et al*, 2012) .

The *i-th* particle in the population (swarm) can be represented by

$$\mathrm{Xi} = (\mathrm{Xi},1,\mathrm{Xi},2,\ldots\ldots\ldots\ldots\ldots,\mathrm{Xi},\mathrm{d}) \tag{1}$$

In the d-dimensional search space. The velocity can be represented as

$$\mathrm{Vi} = (\mathrm{Vi},1,\mathrm{Vi},2,\ldots\ldots\ldots\ldots\ldots\ldots..,\mathrm{Vi},\mathrm{d}) \tag{2}$$

The best previous position of the i-th particle in the swarm can be given as

$$\mathrm{Pbest\ i} = (\mathrm{Pbest\ i},1,\mathrm{Pbest\ i},2,\ldots\mathrm{Pbest\ i},\mathrm{d}\ ) \tag{3}$$

The best means optimal value in PSO and G_{best} is the index of the best particle in the swarm. The adaptive rules of the velocity can be calculated as (H Dorrah *et al*, 2010)

$$\mathrm{Vi},\mathrm{m}\ (\mathrm{k}+1) = \mathrm{w}.\mathrm{Vi},\mathrm{m}\ (\mathrm{k}) + \mathrm{c1}.\mathrm{r1}(\mathrm{Pbest\ I},\mathrm{m} - \mathrm{Xi},\mathrm{d}\ (\mathrm{k})) + \mathrm{c2}.\mathrm{r2}(\mathrm{Gbesti},\mathrm{m} - \mathrm{Xi},\mathrm{d}\ (\mathrm{k})) \tag{4}$$

And the position is calculated as in

$$\mathrm{Xi},\mathrm{d}\ (\mathrm{k}+1) = \mathrm{Xi},\mathrm{d}\ (\mathrm{k}) + \mathrm{Vi},\mathrm{d}\ (\mathrm{k}+1) \tag{5}$$

Where i=1…n; m=1…d, and n: Size of the swarm (No. of birds). d: Dimension of the search. k: Iteration numbers. w : Momentum of inertia. c1, c2 : Constants of acceleration. r1, r2 : Random numbers.

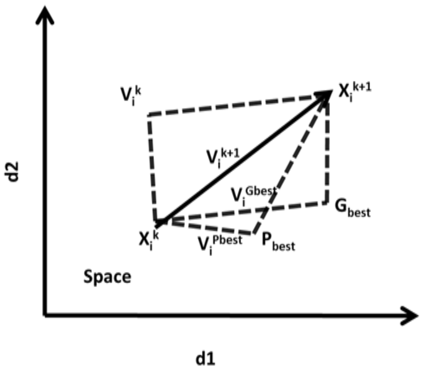


Fig.1 The updating of the searching point in PSO

X_i^k : Current position of the particle in the group.
X_i^{k+1} : New position.
V_i^k : Current velocity of the particle in the group.
V_i^{k+1} : New velocity.
V_i^{Pbest} : Velocity based-on best position of particle.
V_i^{Gbest}: Velocity of the particle based-on G_{best} Group.)

Each particle adjusts its trajectory towards the best solution. The fitness function evaluates the performance of particles to determine whether the best solution is incurred (Allaoua *et al*, 2009) .The performance index (PI) may be selected as one of that given in equations (1). The fitness function (α) is given by

$$\alpha = 1/PI \quad (6)$$

2.3 PSO-Tunned PID Controller

The PSO algorithm is applied to both plants simultaneously described in Fig. 2 individually. The PID parameters are optimized for each case. Figure 2 shows the block diagram of using PSO algorithm for tuning the PID parameters as a general scheme for tuning PID by PSO. The error value is used to calculate the PI and the fitness function is then used to tune the parameters of the PID controller according to PSO algorithm which has been previously discussed (Zhao *et al*, 2005).

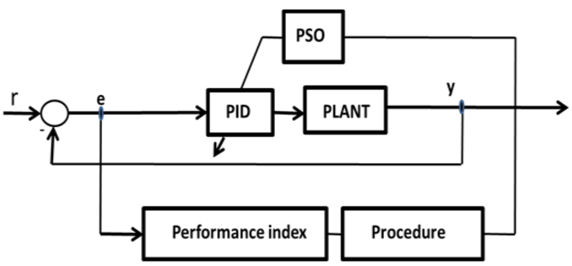


Fig.2 Block diagram of PSO tuning method for single plant

3. Proposed Multi Plant Description Model

The proposed MPMC system ıs that one illustrated in schematic diagram of Fig. 3. For more simplicity in analyzing, the system has been decoupled into two parts, the first is the plants (DC motors) built in a card as depicted in Fig. 4, while the base station (Controllers) card is presented as in Fig.5 separately in order to achieve the optimal values of the system parameters.

The entire system is designed to control and monitor the speed of two plants (DC motors) and return feedback if the speed exceeded the set value. The ZigBee technology is utilized for wireless connection between the system parts. This module provides a low power WSN and cost as well as designed to meet up with IEEE 802.15.4 standards. Reliable data are offered to transmission between the devices using this module (Park *et al*, 2017; Vidgren, *et al*, 2013).

The GUI designed in the LabVIEW program is the base station which controls the entire system. The LabVIEW defines as the environment of programming to control the hardware. It is a language graphically focused on icons rather than a set of simulation programming codes. The system consists of two parts the station part and the sensing part that will be shown in the next section (Ramprakash, *et al*, 2015).

The station consisting of a PC, Arduino Uno, two ZigBee modules. The first ZigBee work as a transmitter and the second ZigBee works as a receiver. The purpose of this part is to take control signals from GUI and sending them to the sensing part and then receive feedback from the sensing part wirelessly using the ZigBee modules.

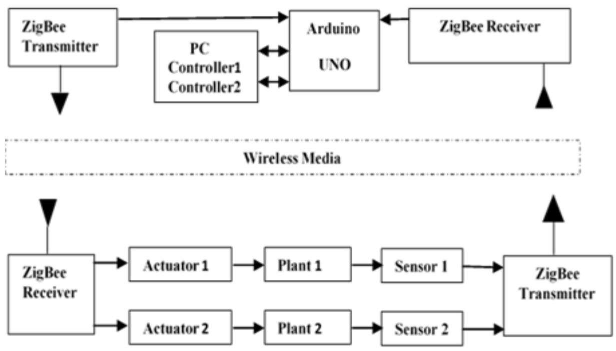


Fig.3 Schematic diagram of proposed system

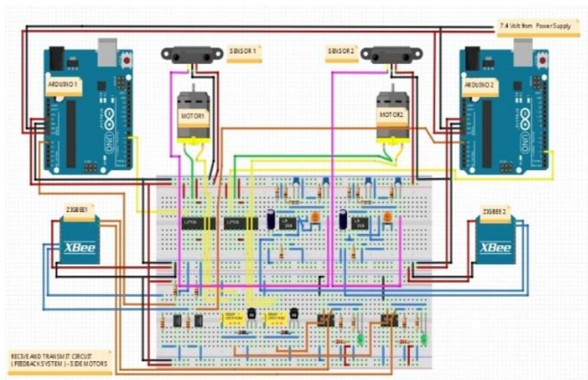


Fig.4 Multiple plant card

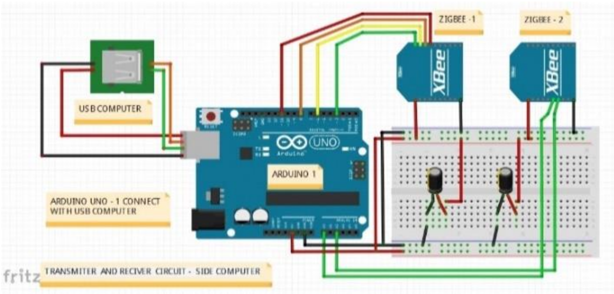


Fig.5 Multıple Controller card

The MPMC is one of the systems that featured with high non linearity, complexity and it constrained with cross coupling between the two plants connected wirelessly with controllers. It can be considered as challenging engineering problem.

All appliances in this part such as DC motors, sensors, Arduino Uno, ZigBee module, relays module, and MCU pic 12F675, etc. will be supplied by using two battery ion-lithium connecting respectively. A switch is connecting respectively with the two batteries and with the circuit to control turn on and turn off the sensing part. Each DC motor has its specific Arduino Uno, photocoupler, LM393D, MCU pic 12F675, transistor and relay etc. .

This part receives control signals from the station part through the first ZigBee and gives it to two motors after passing through Arduino Uno, photocoupler, and LM393D to analyze signals and save Arduino from damage because of high drawing to current. The speed sensors module determines the speed of each motor and sends it to the second ZigBee and it, in turn, sends it to the station unit. After that, if the speed of the motors greater than the value we set the station will return the feedback signal to the sensing part through ZigBee.

The feedback signal receives from MCU pic 12F675 and it's programmed to make a delay of 10 sec for motors. After 10 sec if the dc motors speed stabilizes the motors continuous run else that the motors will turn off. Relays module responsible for turn off motors after receiving signal from pic 12F675 through transistors. Fig.6 shows the connection of the power supply unit in Fritzing program.

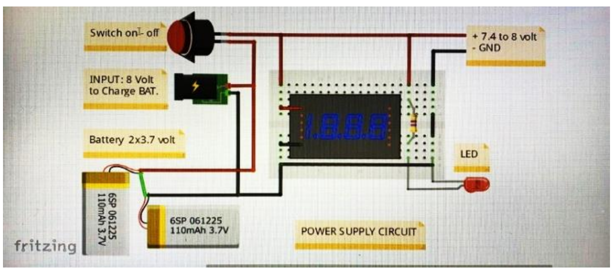


Fig.6 Connection of the power supply part

The main problem of controlling and monitoring the DC motors speed has led to the design of a wireless close loop control system for the speed of two DC motors. The designs are therefore implemented as the station part and the sensing part each unit works as sender and receiver at the same time. Fig.7 shows the block diagram of the system in the LabVIEW program.

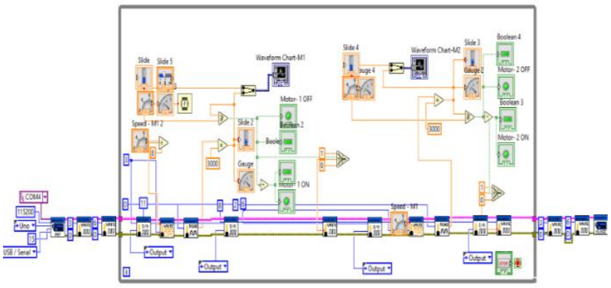


Fig.7 The block diagram of the system

4. System implementation

The station part is operated to continue to control and monitor the speed of the DC motors. The station is represented in simple form by the Arduino Uno, Two XBee S2C, serial cable, PCB Vero board, and PC. Fig.8 shows the implementation of the base station which contains two controllers 1 and 2 built in PC by using LabVIEW program.

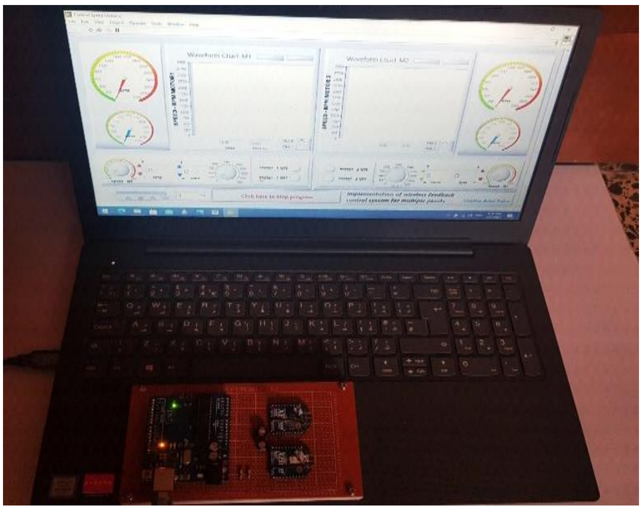


Fig.8 Pictorial diagram of the base station (Controllers)

4.1 Implementation of the sensing part

The implementation of the sensing part is done by connecting two driver motor, two photocouplers, two integrated circuit converter frequency to voltage, two battery lithium-ion, two-transistor MPS2222A, two ZigBee XBee- PRO, resistors, capacitors with two Arduino Uno and two relay 5v, two infrared LM393 speed sensor with two dc motors module and Vero board as shown in Fig.9.

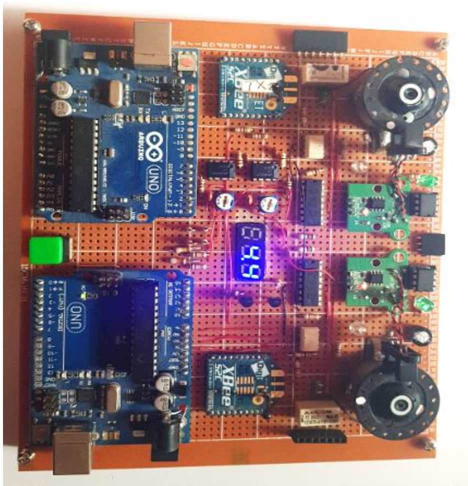


Fig.9 Pictorial diagram of the base station (Controllers)

For more details of the derivation of the models and their respective definition of constants and variables the reader can return (Jain *et al*, 2019).

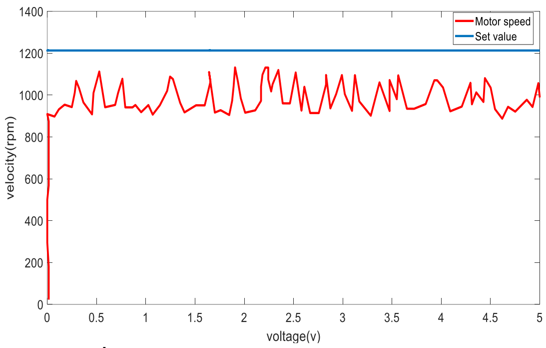


Fig.10 İnput-output data for MPMC system

For simplification of work, two models have been developed for one degree of freedom (1DOF) for plant 1 and plant 2 using system identification tool box of Matlab as can be shown in Fıg.10. The data is obtained from the real time experiments. The transfer function of the first plant (DC motor) can be given as

$$G_{p1}=\frac{V}{v}=\frac{2.45}{S^3+1.5S^2+4S+5} \quad (7)$$

And the transfer function for the second one is

$$G_{p2}=\frac{V}{v}=\frac{2.43}{S^3+1.3S^2+4S+3.9} \quad (8)$$

Where *V* is the velocity *(RPM)* and *v is* the input voltage *(Volt)*

4.2 Traditional PID Tuning Method

A lot of methods have been developed for adjusting the parameters of the PID controller such as Z-N a second method, Coohen-Coons method and Astrom and Haggland method (Juang *et al*, 2008). The closed loop tuning method of Z-N is used and it depends on the ultimate value of gain G_u and ultimate period of oscillation T_u. The tuning rules for finding the gains of the PID parameters are given as

P controller: $K_p= 0.5G_u$
PI controller: $K_p= 0.45G_u$; $T_i = T_u /1.2$
PID controller: $K_p= 0.6\ G_u$; $T_i = 0.5T_u$; $T_d =T_u /8$

The complete procedure can be found in [19] and references therein. The simulation results for using this method. Both plants controllers parameters will be compared with that obtained from PSO method. The tuned parameters are summarized in Table 1.

Table 1. PID parameters using Z-N second method

System	K_p	T_i
Plant1	1.256	21
Plant2	2.77	0.5

5. Simulation Results

5.1MPMC Settings

The simulation results for PI controller based-on PSO algorithm is implemented by using Matlab/Simulink environment. The Simulink representation of the tuning method using PSO algorithm for both plants depends on Fig.2. The factors that are used in building the Matlab code are defined in Table 2; meanwhile Table 3 summarizes the fitness function values required for different methods which have been defined in (1) to (4). The fitness function which has been used in simulation is ITSE.

Table 2. The PSO parameters

System	N	D	W	c1	c2
Plant 1	50	2	0.8	1.1	1.1
Plant 2	50	2	0.4	1.4	1.3

To achieve the optimal performance, the choice is done through the selection of the criteria and the PSO algorithm factors. The results obtained can be illustrated in Fıg. 12 and13 which show the best tuning of the PID controller parameters using the PSO algorithm.

5.2 Performance Evaluation

The results of the tuning method by using PSO are shown in the following figures. In Fig.11 the cost function is illustrated which affect to the change of optimal values of Kp, Ki, Kd while, Fig. 12 (a) and (b) show the step response of the first and second plants, respectively, for the Ziegler-Nichols method (Z-N), PSO method and the existed real time experiment (EXP) compared according to the reference at the same plot.

The PID parameters that have been obtained by the PSO method give the better response. In this paper, a time domain criterion is used for evaluating the PID controller. A good step response that will result in performance criteria minimization in the time domain can be obtained from a set of good controller parameters. For optimal MPMC control system, the system is tested with disturbance by applying a sudden load on the motor shaft which leads to decreasing the speed of motor to a certain value as can be illustrated in Fıg.13 (a) for the first plant and (b) for the second one.

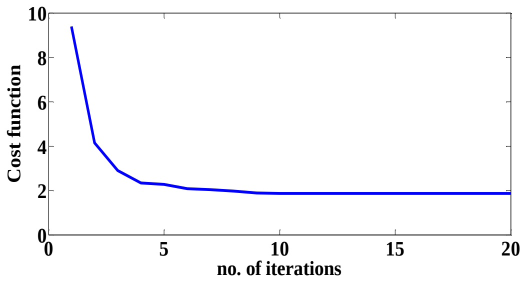
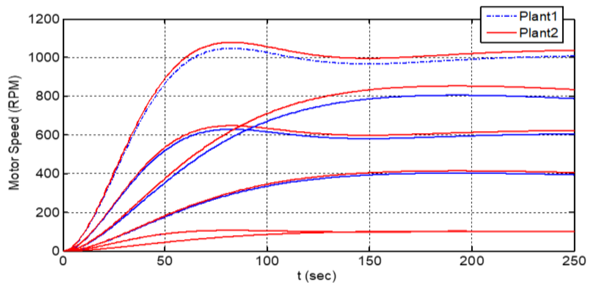
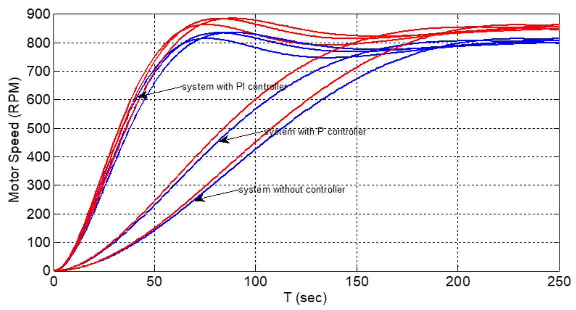


Fig. 11. Optimal PID controller parameters based PSO for the two plants of MPMC cost function

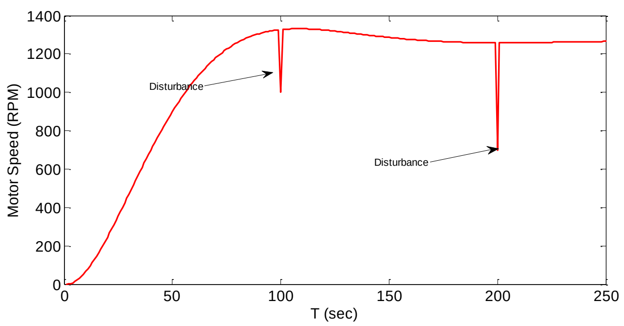


(a)

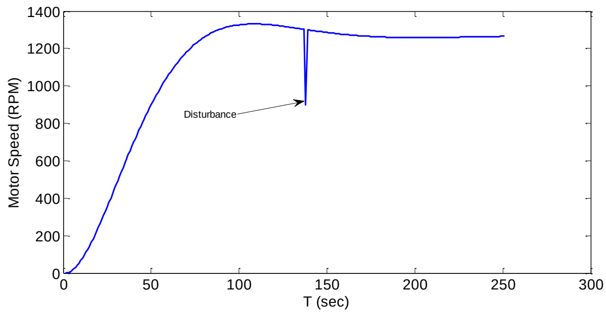


(b)

Fig. 12. Predicted step response of MPMC system for three tuning methods. (a) plant 1 (b) plant 2



(a)



(b)

Fıg. 13 MPMC system under disturbance (a) Plant 1 (b) Plant 2

Table.3 Summary of PID parameters for three methods

Method	Plant 1			Plant 2		
	Kp	Ki	Kd	Kp	Ki	Kd
EXP	1.7	1.5	0	4.9	8.3	0
Z-N	4.6	0.82	0	2.8	4.09	0
PSO	2.57	7.32	0	2.99	0.004	0

The parameters of the PID controller for three methods are summarized in Table 3 and for both plants of MPMC separately. The interaction effects due to cross coupling between the two planes; vertical and horizontal is not taken into account in the experimental and Z-N methods. In the PSO method, the interaction effects between the planes is embedded in the mathematical model, since the data for identification is taken experimentally from a real MPMC system.

Conclusions

The ZigBee technology was utilized to send and receive data between the sensing part and the station part wirelessly. Arduino Uno in the station part represents the link between the S.W and H.W of the system. GUI designed in LabVIEW is the part that controls the entire system. Successful cost reduction is linked to the construction of a wireless system.

Optimal parameters for the PID controller have been found using PSO algorithm. The models of the TRMS have been found from a real time experiment data. The models of the TRMS are found using system identification tool box of Matlab. The results show that the PSO based PID controller can perform an efficient search to find optimal set of parameters. The performance of the system with PSO is better than the conventional method.

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