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Lighting System Optimisation Design using Solatube with GA-PID Controller

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ABSTRACT

A Solatube is a daylight system that used to save electricity generated from nonrenewable energy sources. However, the amount of solar entering the room via the Solatube had not been controlled. The goal of the research is maintaining a more consistent light intensity of 350 Lux for 24 hours. The study attempts to create a lighting optimization system based on an experimental design based on a PID controller. The system consists of a microcontroller, a light sensor, some motors and drivers. The PID parameter is tune beginning with the Ziegler-Nichols method and optimizing it with the Genetic Algorithm (GA) approach. The GA approach produced the best results with a population of 50, a K_p value of 0.105210, a K_i of 0.052901, a K_d of 0.046443, and a tuning time of 94 seconds. The annual savings value of using electrical energy is 22.07%.

Keywords: *Solatube, Lighting Lamps, PID Controllers, Genetic Algorithm (GA), Energy Saving*

ABSTRAK

Solatube adalah sebuah sistem pencahayaan ruangan yang digunakan untuk menghemat listrik yang dihasilkan dari energi yang tidak terbarukan. Namun, jumlah sinar matahari yang masuk ke ruangan melalui Solatube belum diatur. Tujuan riset ini adalah menghasilkan intensitas cahaya yang lebih stabil pada 350 Lux sepanjang hari selama 24 jam. Penelitian ini mencoba merancang sistem optimasi pencahayaan dengan metode desain eksperimental berbasiskan pengendali PID. Sistem terdiri dari sebuah mikrokontroller, sebuah sensor cahaya dan beberapa motor dengan penggeraknya. Penalaan parameter PID dimulai dengan metode Ziegler-Nichols dan mengoptimalkannya dengan metode Algoritma Genetika (GA). Hasil terbaik diperoleh dengan metode GA dengan jumlah populasi 50, dengan nilai K_p = 0.105210, K_i 0.052901, dan K_d = 0.046443, dengan waktu tuning 94 detik. Nilai penghematan dalam penggunaan energi listrik adalah 22,07% per tahun.

Keywords: *Solatube, Pencahayaan Lampu, Pengendali PID, Algoritma Genetika (GA), Pengehamatan Energi*

1. INTRODUCTION

Right now, energy efficiency is a crucial concern. To sustain the quality of life in this world, we must take several energy-saving measures, mainly by lowering our reliance on nonrenewable energy sources. New energy sources will emerge as a feasible solution to the energy dilemma as the world's demand for clean energy develops. Although energy storage is becoming more popular, lowering energy usage is the most effective strategy to conserve energy **(Hodges and Flick, 2017) (Nugraha and Adriansyah, 2022)**.

One technique to make buildings more energy efficient is to reduce the amount of electricity consumed for lighting. Natural light from the sun has the ability to minimize carbon footprints and, ultimately, environmental repercussions. **(Nihmiya, 2021)(Nugraha and Adriansyah, 2022) (Bohani et al., 2022)**. Solar energy, which can be transformed into electrical energy, is one of the most prominent renewable energies today. Using sunlight as natural light indoors can also help minimize energy use. Studies have shown passive lighting solutions save 20–30% of overall power consumption **(Balabel et al., 2021)**. Aside from lighting the room, sunlight can be employed to reduce energy use during the day **(Chi et al., 2018)**. Then, lighting is a crucial consideration when constructing a room. The room is lit by three sources: lamplight, blinds, and sunlight. This room's light source is ultimately intended to provide visual comfort **(Babarinde and Alibaba, 2018)**.

However, excessive sun exposure can induce light pollution, overheating, and visual difficulties **(Singh et al., 2013)**. According to research, a guiding structure that spreads to provide optimal lighting levels **(Malet-Damour et al., 2020)**. So, if the quality can be changed so that the outcomes are pleasant for humans, we can reap the benefits of natural light **(Wong, 2017)**. Therefore, optimizing the amount of light a person or room can receive, visual comfort and perceived coolness, and energy savings are all aspects of effective light source design **(Susanto et al., 2018)**. Depending on the room's location, natural light sources can be challenging to find. A basement partition, for example, that is too narrow or dark, even during the day, due to impediments in the space, or an office partition in a vast room.

Solatube is a gadget that may be used to maximize the use of sunlight in a room without photo ventilation **(Iqbal and Ahmed, 2014) (Hodges and Flick, 2017)**. Solatube is a tube sleeve that directs sunlight from a building's roof to an enclosed room where a light source is required. A study explains the implementation of a novel natural lighting approach **(Malet-Damour et al., 2020)**. When compared to direct sunlight, employing Solatube lowers the excess of transmitted light. Furthermore, it aids in reducing the excessive temperature rise in the room. The study explains many natural lighting system prototypes **(Whang et al., 2019)**. Solatube can conserve energy and has a high economic value of 1% to 79% of indoor light usage during the day in this situation **(Fauziah et al., 2021)**. Solatube is also ideal for smart cities because it adheres to the energy-saving principle **(Alzaed and Balabel, 2020)**. According to studies, combining Solatube and dimmer settings can save up to 27% on power **(Shin et al., 2012)**.

Furthermore, because Solatube just reflects light, it will not cause light leaks in our homes. Sunlight enters the pipe as a light source and is directed to the pipe's inner wall, which is covered with a mirror-like layer as a reflector. The tube's light is subsequently directed into the room. The Solatube system's light intensity results can be used to satisfy the needs of room light intensity. The structure of a Solatube is depicted in Figure 1. More information about the system of Solatube can be found in our previous research **(Koerniawan et al., 2022)**.

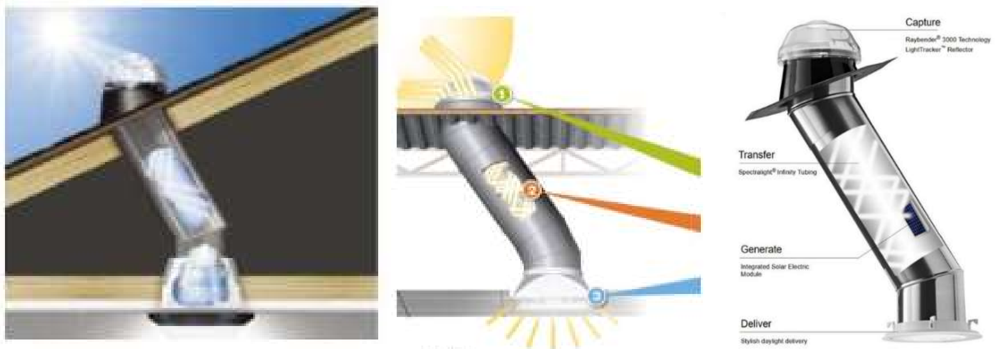

Figure 1. A Solatube System (NN, 2022)

Several publications cover a wide range of subjects relevant to energy efficiency and conservation. These include employing energy-efficient lighting, air conditioning systems with more energy-efficient inverters, and installing solar panels to save energy. Previous research has investigated energy efficiency through the use of integrated solar energy in both photovoltaic and smart-grid photovoltaics **(Gerber et al., 2019) (Opoku et al., 2020)**. However, using solar cells and batteries to absorb electrical energy from sunlight remains a weakness due to their high cost. Therefore, solar energy necessitates more cash and more complex installations.

According to another study, using Solatube as a sustainable energy source produced from solar energy for lighting is an energy-saving alternative, employing natural light from the sun without needing electricity **(Balabel et al., 2021) (Alzaed and Balabel, 2020) (Opoku et al., 2020) (Ovcharov and Selyanin, 2016)**. However, there is no mechanism for controlling the intensity of sunlight entering the room through the Solatube. Therefore, only research on the benefits of Solatube as a lighting alternative was done. And in his study, he explained the proposal to continue research by adding control settings to regulate the amount of incoming sunlight to aid visual comfort **(Babarinde and Alibaba, 2018)**. Therefore, an energy-efficient lighting system was developed by integrating bulb dimmers and Solatube **(Fauziah et al., 2021)**. This combination is intended to maximise natural resources from sunlight as a light source in spaces without light ventilation to attain the appropriate intensity with minimal bulb power consumption. However, due to the lack of control for opening and closing valves that may be moved automatically to modify the intensity of light produced by Solatube, there are still flaws in the research being undertaken. On a clear day, the condition was required because the sun shone clearly, and vice versa. Solatube produces light that is brighter than 350 Lux and even brighter than 450 Lux. Of course, this disrupts the comfort of those present. Furthermore, the room will feel hotter.

According to Tiwari et al., the Genetic Algorithm (GA) is the best algorithm for determining the ideal Proportional, Integral, and Derivative (PID) controller values for DC motor speed **(Tiwari et al., 2018).** When compared to typical or classical approaches, such as the Ziegler-Nichols Method, PID parameters set with GA have a faster response. The conventional method is utilized to generate the initial value of the PID parameter, which is then used to assess the optimized parameters via a GA. This method will produce superior overshoot and rising time findings.

Therefore, it is vital to develop ideal lighting sources to regulate the amount of light that can be received while maintaining comfort and cooling the visual senses. To get good control results, this paper uses a microcontroller to control the Solatube valve and dimmer bulb. It is anticipated that it will accomplish precise and efficient valve positioning. The quantity of light that enters the room correlates to the amount of light Lux, which is more consistent at 350 Lux and lowers flickering **(Ji et al., 2016)**. At this 350 Lux condition, the eyes are comfortable, and the room's temperature and heat are maintained as expected. It also has a light dimmer to keep the light constant in cloudy, rainy, or nighttime settings.

The following portions of this paper are organized as follows: Section 2 discusses research methods. Section 3 contains the findings and discussion. Section 4 is the final section.

2. METHOD

2.1 Research Methods

In this experiment, three phases are completed. The initial step is to create the system model. Second, the study attempts to put the system concept into action. Third, it puts the system architecture to the test in order to achieve a consistent and unblinking lighting intensity of 350 Lux.

Figure 2 depicts the system block diagram that will be designed. The system model comprises the Solatube system block, the system-built block, and the control system block. The Solatube system block is made up of the capture zone, transfer zone, Solatube valve, and delivery zone. Meanwhile, the system-built block is made up of a dimming lamp, a BH1750 light sensor, a DC and stepper motor, and a Solatube tube. At the same time, the control system block includes a power system, XG 398 module control of the dimmer lamp, Arduino UNO R3 controller, and L298 N motor driver. This control system also comprises PID Controller software for tuning with Ziegler-Nichols and GA. Figure 3 depicts the hardware design for the system.

Establishing the K_p, K_i, and K_d values for the PID Controller begins with selecting the set point at 350 Lux. The K_u value is then determined through trial-and-error trials until a stable wave oscillation is produced in order to acquire the frequency value and the mid-wave value based on the set point, which is 350 Lux. After obtaining the K_u value for the frequency, the Ziegler-Nichols method can be used to auto-tune K_p, K_i, and K_d. Following the formation of Ziegler-Nichols K_p, K_i, and K_d values, the GA is performed to obtain optimised K_p, K_i, and K_d values with a specified population size. Population is a set of chromosomes that a subset of solutions in the current generation. The K_p, K_i, and K_d values obtained from the GA auto-tuning will be entered into the DC stepper motor parameters in response to actuating the Solatube valves.

The light sensor will detect changes in light intensity in the room caused by the Solatube and the lights. If the light level changes between 0 and 349 Lux, the sensor will send a signal to the Arduino Uno control to handle the situation. The Arduino Uno will then send a signal to the motor driver to direct the stepper motor to open the valve until a light of 350 Lux is reached. The active limit switch indicates that the valve is entirely open if it is 100% open. If the light received by the sensor does not exceed 350 Lux, Arduino Uno will send a signal to the dimmer module to turn on the light until it matches the setpoint, which is 350 Lux.

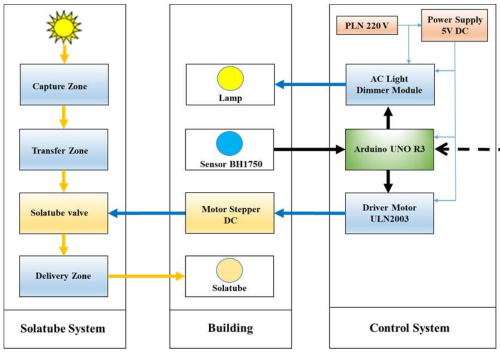

Figure 2. System Block Diagram

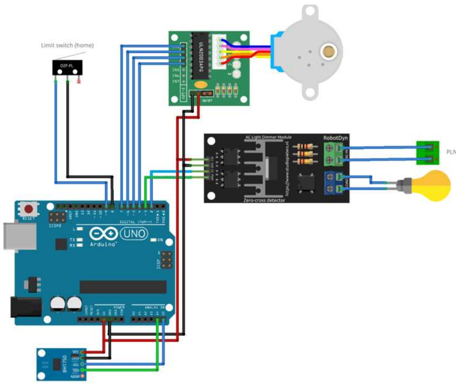

Figure 3. Hardware Design

Even if the lamp is turned out at night, the control procedure can still function. It has been found that the Lux size for the installed lights can reach 350 Lux, so without a Solatube light at night, the installed lights will generate 350 Lux of light. Figure 4 depicts the lighting control system flowchart.

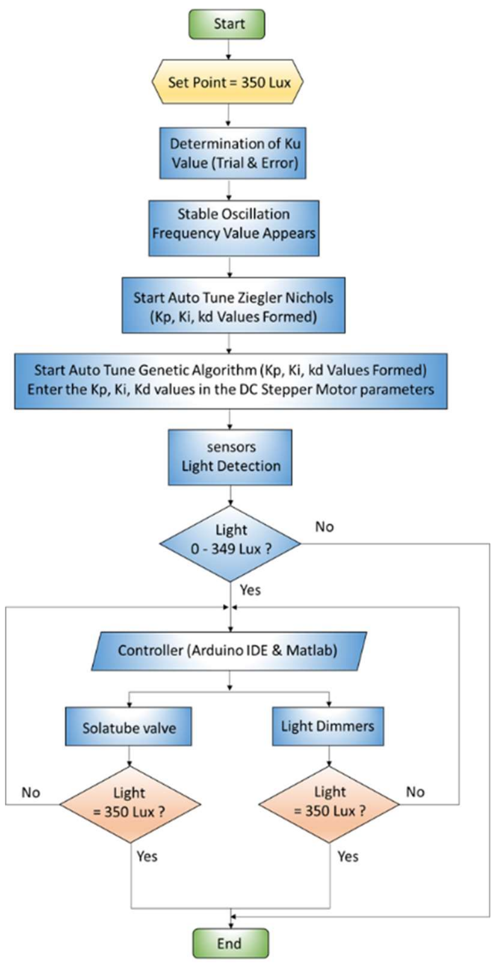

Figure 4. Flowchart of the Lighting Control System

2.3 Software Design and Realisation

The most extensively used controller in the industry is the proportional integral derivative (PID) controller. To improve performance, the PID controller can control the speed of DC stepper motors. The reaction performance of a DC stepper motor is tested using characteristics such as settling time, rising time, overshoot, and steady-state error. Equation 1 gives the PID output based on the reference error.

$$U(t) = K_p\, e(t) + K_i \int_0^1 e(t)dt + K_d \frac{de(t)}{dt} \tag{1}$$

Where:
U(t) = Derivative Action (Derivative of error)
K_p = Proportional Gain
K_i = Integral Gain
K_d = Differential Gain
e(t) = Errors

The PID system's purpose is to control the plant. Because most of the problems are challenging to model in the plant, modelling the complete system is equally complex. PID tuning with Ziegler-Nichols requires K_u data from direct measurement (feedback signal), so the controller and the device under control must be stable for testing.

It can utilise an optimisation approach based on the transfer function or the following procedure to obtain the values of K_p, K_i, and K_d:

1. It begins with a K_p (Proportional Gain) value. Reduce the rise time value and avoid providing a K_p value that is too large or too small.
2. Once the response is satisfactory, provide the value of K_d (Derivative Gain). This is done to minimise the amplitude of the oscillations so that they can be muted or eliminated.
3. The final step in determining the gain value is to calculate K_i (Integral Gain). If the system state reveals a steady state error, if there is a difference between the setpoint and the system value when a steady state is reached, Ki modification is required.

Especially when using the Ziegler-Nichols method, then:

1. Create a simulation or tool that can represent the model
2. Set K_i and K_d = 0
3. Run the simulation or tool
4. Look at the system response by entering the Kp value from 0 to K_u (where the response condition is stable/stable oscillation will be obtained)
5. Calculate the values of K_p, K_i, K_d, T_i and T_d based on the following Ziegler-Nichols constant:

$$K_p = 0.6 * K_u \tag{2}$$

$$K_i = K_p / T_i \tag{3}$$

$$K_d = K_p * T_d \tag{4}$$

$$T_i = 0.5 * PU \tag{5}$$

$$T_d = 0.125 * PU \quad (6)$$

$$PU = (2 * pi)/f \quad (7)$$

GA Tuning fulfils the same function as Ziegler-Nichols Tuning. This is done to determine the best K_p, K_i, and K_d values for P, PI, and PID control parameters and to set the speed of a DC stepper motor. The Ziegler-Nichols adjustment calculates K_p, K_i, and K_d values through trial and error. Using tha GA parameters, optimal K_p, K_i, and K_d values are derived as P, PI, and PID control parameters in the genetic algorithm.

The tuning of the GA starts with the start-up of the individual population. The DC stepper motor's parameter is the individual. The plant that generates the chromosomes in the process is used to estimate the parameters. Following the population's initialisation, each individual's fitness value is calculated. Selection, reproduction, and mutation are then used to create the next generation. This operation is repeated until either the smallest error or the maximum number of iterations is reached.

The population and the size or number of iterations have an impact on the solution search process. There is no optimal population size or iteration for all case studies. The GA procedure may not offer high-quality solutions if the population and iteration sizes are too small. Conversely, too many iterations and population sizes can complicate GA computations. Various studies used trial-and-error experiments to investigate the effect of population size and iteration on the resulting solution. Experimenting with population size and iterations within a particular range yields a solid solution. However, outside of this range, the optimisation results are unsatisfactory. This study chose the population size and replicated through a trial-and-error approach. All simulation and calculations processes, such as determination of K_u value, Ziegler-Nichols and GA for PID parameters tuning are using Matlab.

3. RESULTS AND DISCUSSION

3.1 Model Design and Hardware Realization

To carry out this research, hardware in the form of a Solatube model system and lighting mounted in a room box is required. The room box is made of cardboard covered in black cloth and is 37 cm by 31 cm by 32 cm in length, breadth, and height, with a 7.5 cm diameter Solatube pipe sheath and a length of 30 cm. Then, a sensor is required to detect the intensity of the light emitted by the Solatube and lights. Arduino Uno, dimmer modules, motor driver modules, and DC stepper motors as Solatube valve activators must also be considered when arranging them in the model room. Figure 5 depicts the front and back views of the Solatube system and the room models that have been created. The figure also shows where the Solatube pipes, DC stepper motors, limit switches, room lights, light sensors, the Arduino Uno controller, and the dimmer and motor driver modules are located.

3.2 Simulation Results

PID tuning using Ziegler-Nichols requires K_u data. The K_u value is obtained from the trial and error results run on the system. The value of K_u cannot be too big or too small. After the experiment was carried out, the K_u value was obtained between 0.0 to 1.12. Following that, the initial values of K_i and K_d are found to be equal to zero, allowing the system to run. The desired system reaction will then be seen.

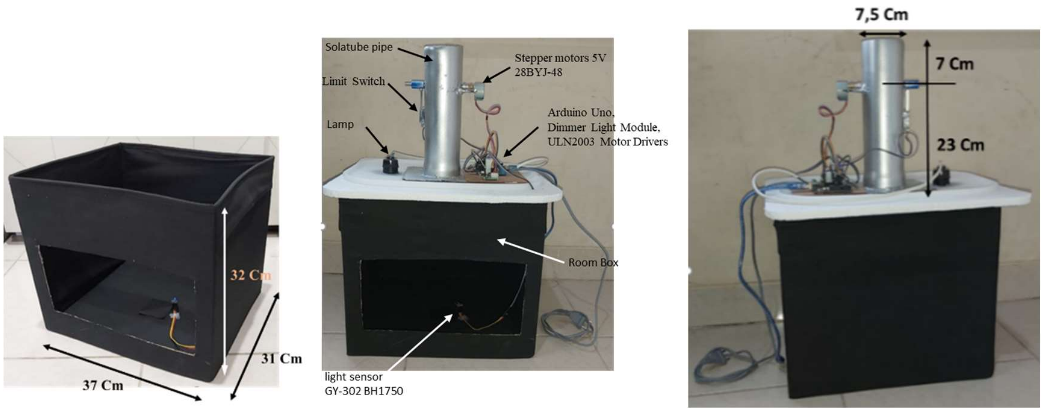

Figure 5. The Space Model

So, the values of K_p, K_i, K_d, T_i, and T_d may be computed using Equations 2–7 based on the Ziegler-Nichols constant and the frequency values of the oscillating waves that occur. Table 1 shows the simulated K_u values and the mean and frequency results. The set point system is set to 350 Lux. All simulation processes are used Matlab.

The best value of K_u is determined from the trial-and-error results, namely 0.17, resulting in the midway value of the set point corresponding to the intended set point, namely 350 Lux. The obtained steady frequency is 1.6667 Hz. Figure 6 depicts the results. After that, it may begin to calculate the K_p, K_i, and K_d values from this data and prove them through several tests. The light Lux graph is derived from the experimental findings, as shown in Figure 7.

After extracting the frequency magnitude from the value of K_u = 0.17 of 1.6667, the Ziegler-Nichols tuning may be conducted. It produces a value of K_p = 0.102, K_i = 0.05411, and K_d = 0.04807, with a resulting illumination value of 350.83 Lux. The number is 0.83 Lux higher than the present value of 350 Lux.

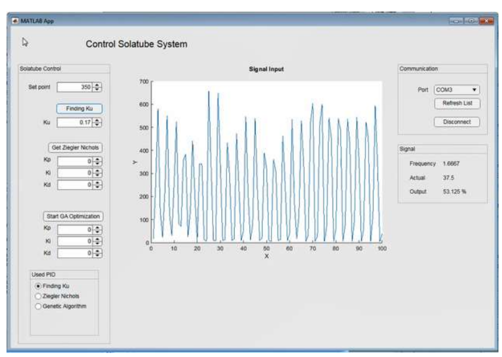

Figure 6. Graph of frequency findings
X-axis shows Time (seconds), Y-axis shows Light Intensity (Lux)

Table 1. K_u values along with the results of the midpoint set point and frequency values

No.	K_u value	Middle-value Set Point	Frequency Value
1	0.00	0	0
2	0.01	3.4	0
3	0.02	4	0
4	0.03	5.8	0
5	0.04	10	0
6	0.05	17.5	0
7	0.06	29	0
8	0.07	37	0
9	0.08	53	0
10	0.09	67	0
11	0.10	83	0
12	0.11	97	0
13	0.12	110	0
14	0.13	175	1.6667
15	0.14	225	1.6667
16	0.15	250	1.6667
17	0.16	300	1.6667
18	0.17	350	1.667-1.771
19	0.18	400	1.6667
20	0.19	400	1.6667
21	0.20	450	1.6667
22	0.21	450	1.6667
23	0.22	500	1.6667
24	0.23	500	1.6667
25	0.24	500	1.6667
26	0.25	500	1.6667
27	0.26	500	1.6667
28	0.27	600	1.6667
29	0.28	600	1.6667
30	0.29	600	1.6667
31	0.30	600	1.6667
32	0.31	600	1.6667
33	0.32	600	1.6667
34	0.33	600	1.6667
35	0.34	600	1.6667
36	0.35	600	1.6667
37	0.36	600	1.6667
38	0.37	600	1.6667
39	0.38	600	1.6667
40	0.39	600	1.6667
41	0.40	600	1.6667
42	0.45	600	1.6667
43	0.50	600	1.6667
44	0.55	600	1.6667
45	0.60	600	1.667-1.771
46	0.65	600	1.6667
47	0.70	600	1.6667
48	0.75	600	1.6667
49	0.80	600	1.6667
50	0.85	600	1.6667
51	0.90	600	1.6667
52	0.95	600	1.6667
53	0.96	600	1.6667
54	0.97	500	1.6667
55	0.98	600	1.6667
56	0.99	500	1.6667
57	1.00	500	1.6667
58	1.01	995.5	0
59	1.02	1000.5	0
60	1.03	997.5	0
61	1.04	998	0
62	1.05	997	0
63	1.06	998.3	0
64	1.07	998.5	0
65	1.08	998.5	0
66	1.0	999	0
67	1.10	1001	0
68	1.11	998	0
69	1.12	1000	0

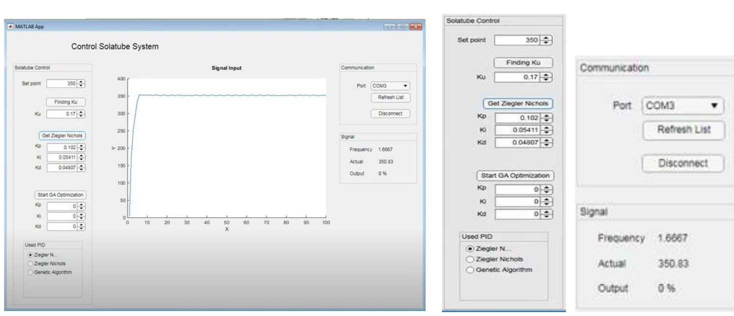

Figure 7. Graph of the findings of Lux values and Kp, Ki, and Kd values using the Ziegler-Nichols method

The results of Ziegler-Nichols' K_p, K_i, and K_d values are then used to determine ideal K_p, K_i, and K_d values using the GA's optimisation process. This study employs various population estimates, ranging from 10 to 300. The best K_p, K_i, and K_d values are obtained from all of the experimental data. Table 2 shows the K_p, K_i, and K_d Kd values derived from the experimental data. Figure 8 shows the results of a simulation-generated graphic image based on the number of populations used for GA. With a population of 50, the length of time for auto-tuning is 94 seconds.

Table 3 shows a collection of results from experiments with eight different population numbers, with repeated auto-tuning for each of the same population three times.

Table 2. Results of K_p, K_i, and K_d values with different population numbers

No.	Total Population	Duration of Auto Tuning Time (second)	Value		
			K_p	K_i	K_d
1	10	35	0.1052	0.05226	0.04881
2	20	49	0.1052	0.05496	0.04777
3	30	64	0.1052	0.05523	0.04927
4	40	79	0.1052	0.05378	0.04735
5	50	94	0.1052	0.05290	0.04644
6	100	171	0.1052	0.05228	0.04876
7	200	321	0.1052	0.05489	0.04770
8	300	471	0.1052	0.05173	0.04975

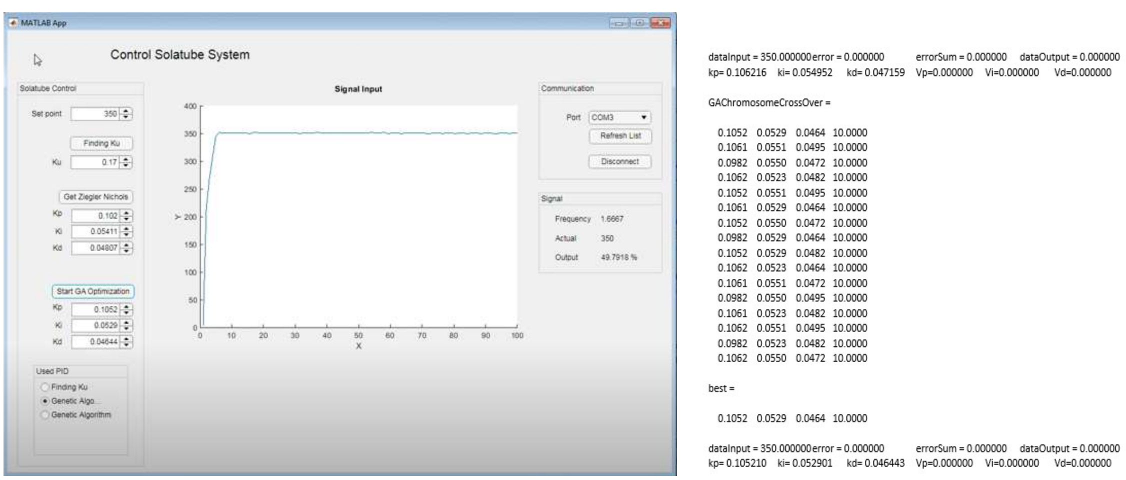

Figure 8. Graphical image of the GA method, total population 50 and K_p, K_i, and K_d values, GA simulation results with 50 populations

Table 3. The results of the auto-tuning experiment 3 times in each population with Set Point 350 Lux

No.	GA Population	PID Value			Data (Lux)		Average Error (%)
		K_p	K_i	K_d	Autotune	After PID	
1	10	0.10521	0.05226	0.048815	349.17	348.33	0.40
					349.17	347.50	
					350.00	350.00	
2	20	0.10521	0.054955	0.047772	350.83	350.83	0.56
					346.67	346.67	
					347.50	351.57	
3	30	0.10521	0.055228	0.049274	351.67	351.67	0.32
					350.00	349.17	
					350.83	350.83	
4	40	0.10521	0.053781	0.047353	351.67	349.17	0.32
					350.00	350.83	
					350.83	351.67	
5	50	0.10521	0.052901	0.046443	350.00	350.00	0.16
					350.00	351.67	
					350.00	350.00	
6	100	0.10521	0.052285	0.04876	349.17	350.00	0.16
					351.67	350.83	
					350.83	350.83	
7	200	0.10521	0.054894	0.047696	348.33	347.50	0.40
					351.67	350.83	
					347.50	349.17	
8	300	0.10521	0.051730	0.049752	350.00	349.17	0.16
					350.83	350.83	
					348.33	350.00	

The color description in Table 3 is as follows: red indicates Lux light below 350 Lux, green indicates Lux light at exactly 350 Lux, and yellow indicates Lux light above 350 Lux. Stable lighting results were obtained at 350 Lux with a population of 50, with an error percentage of 0.16%, with PID - GA values of K_p = 0.105210, K_i 0.052901, and K_d = 0.046443. These results can improve the lighting results produced from the Ziegler-Nichols method which was carried out previously, namely 350.83 Lux. This can prove that the GA method can be used to optimise the results of the Ziegler-Nichols method.

3.3 Comparison of Energy Saving Measurements when using lights for 24 hours non-stop and with Solatube.

Table 4 shows the results of 24 hours of sampling measurements sampled every hour. Table 4 shows that sunlight can be used as lighting for closed rooms during the day. At 6 a.m., 5 Lux, and 6 p.m., 3 Lux, the lowest point of sunlight is generated. The most Lux sunshine is generated around 12.00, 13.00, and 14.00 of 350 Lux. Figure 9(a) depicts a graph of the 24-hour connection between light intensity (Lux) and time. Figure 9(b) depicts the relationship between the amount of LED lamp dimmer power consumed and the time for 24 hours. Figure 9(c) depicts the link between the proportion of incandescent bulb power consumed (%) and the time for 24 hours.

Table 4. Sampling results for measuring light intensity (Lux) and dimmer power (watts)

Hour	Light Intensity (Lux)	Dimmer Power (Watt)	Percentage of Lamp Power (%)
	Solatube	Lamp	
00.00	0	70.7	100
01.00	0	70.7	100
02.00	0	70.7	100
03.00	0	70.7	100
04.00	0	70.7	100
05.00	0	70.7	100
06.00	5	70.3	99
07.00	49	62.7	86
08.00	135	62.7	61
09.00	237	55.7	32
10.00	317	24.5	9
11.00	347	3.9	1
12.00	350	0	0
13.00	350	0	0
14.00	350	0	0
15.00	235	55.8	33
16.00	97	65	72
17.00	33	68.6	91
18.00	3	70.4	99
19.00	0	70.7	100
20.00	0	70.7	100
21.00	0	70.7	100
22.00	0	70.7	100
23.00	0	70.7	100

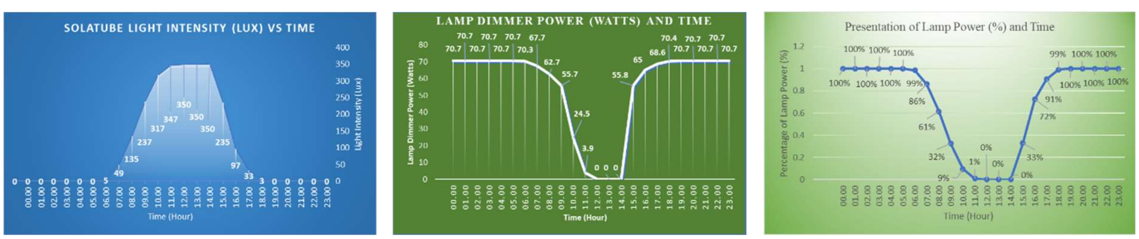

Figure 9. (a) Graphic light intensity (Lux) vs time, (b) Figure 3.7 Graph of lamp dimmer power (watts) and time and (c) Figure 3.8 Graphic presentation of lamp power (%) and time

The energy savings that can be acquired utilising a controlled Solatube and dimmer compared to an incandescent bulb for 24 hours without using Solatube may be computed. It results in annual savings of 22.07%. This research succeeded in providing more accurate and measurable energy-saving data compared to previous studies (**Mesloub et al., 2023**) (**Fauziah et al., 2021**).

4. CONCLUSION

The lamp and solatube illumination is designed to generate a more consistent lighting intensity of 350 Lux. The Ziegler-Nichols method's K_p, K_i, and K_d values still yield a light intensity value of 350.83 Lux. Consequently, the GA method is utilised to optimise the values of the previously determined PID parameters. The K_p, K_i, and K_d values obtained from experimentation were optimised using a GA, generating a more consistent light intensity at 350 Lux according to the supplied set point. The growing population and the longer tuning period do not guarantee that the light intensity will remain steady at the specified point. The utilisation of this regulated solatube results in significant power savings.

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