Real-Time Evaluation Position Control of Directional Wheel Conveyor Using Fuzzy Embedded PLC and SCADA

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Abstract—**This article proposes the position control of the directional wheel conveyor by using fuzzy controller in order to track the setpoint angle. Programmable logic controller (PLC) and camera image sensor were implemented to calculate the output of wheel slip for adjusting the direction of transferring object. The fuzzy rule method is implemented on Omron PLC and operated using SCADA through CX-supervisory software for monitoring and control. The experimental result presents the effectiveness of the setpoint angle position, with superior response of Fuzzy controller. The Fuzzy logic controller is online determined from embedded PLC. The angle position control from this proposed technique can improve position efficiently control directional wheel conveyor.**

Index Terms—**directional wheel, fuzzy logic controller, image processing, programmable Logic controller, SCADA**

I. Introduction

Nowadays, mechanical transmission conveyor is one of the most widely used in many applications: agriculture, industrial and building. Positioning based control of the directional conveyor has become a goal of research topic. Over the last recent years, many intelligent searching and novel algorithms are presented in order to reduce the tracking error. The position control based optimal method is widely used in industrial factory automation plants because that is to maintain target setpoint machine process. The one type of conveyors is a directional wheel conveyor. Many kinds of research are designed to implement and increase performance by control algorithms including adaptive control using tracking error.

Although, we would have to improve the system with control theory. So, many researchers are determining the best response signal, one of the good methods is the optimal gain controller. However, the determination of gain parameters K is not easy. The one of proposing search PID controller gain was developed by John G. Ziegler and Nathaniel B. Nichols [1]. The result of real-time control position motion of the conveyor modified ship heading using Ziegler-Nichols tuning PID gain controller to verify problems [2]. Ziegler-Nichols method determines form signal response open loop to determine gain controller using Ziegler-Nichols general formula. So, calculate the best value in condition rule-based. Concurrently, the Ziegler-Nichols tuning method can be improving the P&O-MPPT performance of a grid-connected solar system and calculate the gain PID controller for the current best situation [3]. It could be used this method to tun PID Ziegler-Nichols and Cohen-Coon method for Multi-tube aluminum sulfate water filter [4] because it is simple. There are a lot of researchers are developing their work to improve its performance. Research [5] present analytic non-fragility justification Ziegler-Nichols to design step response tuning method. In [6] control steam distillation process using PID Controller. In [7] applied calculate PSO in PID control for pendulum system. Many researchers modified Fuzzy Logic based for the example in [8] development of a Fuzzy Logic based static and dynamic obstacle avoidance system for navigation of a mobile robot using vision. In [9] real-time evaluation design and construction of an obstacle avoidance feature for the drone using a fuzzy logic-based controller. In [10] model yields an efficient compromise solution and the overall levels of decision-making satisfaction with the multiple objectives via fuzzy programming using the elevator kinematics optimization (EKO) algorithm including its hybridizations of harmony search and bee algorithms. In [11] presented adaptive fuzzy sliding mode controller for robotic manipulators. In [12] detect fault of rotating machines based on improved adaptive using fuzzy logic controller.

PLC is widely utilized to control machines and there are hardware and software for programming, download (Transfer to PLC) and upload (Transfer from PLC). These older automated systems used many relays. Generally, the PLC is a programmable logic controller used as an assembly of digital or analog logic instruction block functions designed to sequence function chart control and provide Structure text inside. PLC can be programmed with IEC standard programming consist of LAD, ST, IL, FB, and SFC for process control and automatic control in the factory. The PLC SIEMENS step7-200 is used mainly for the control conveyor belt driving and sorting [13]. In [14] use PLC control liquid mixing and bottle filling with proximity sensor, solenoid

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valves, and DC Motors system. Speed control motor of height variation for operation and sorting the lightweight objects which are controlled by PLC [15]. The alarm conveyor systems were designed for coolant and hydraulic using PLC Omron model CJ1M with Ethernet communication module [16]. In [17] present automatic picking and conveying control system using PLC. Current research about control conveyor has been focus it is used in every part of the process in manufacturing to enhance performance the benefit of production, for example, in [18] apply a neural network to predict conveyor energy consumption. In research [19] enhanced the simulation of dc motor using friction model support belt conveyor. In [20] presented saving energy of belt conveyor system by genetic algorithm for optimal control modeling. Belt conveyors are standing and reliable parts. In [21] to design a prototype of automatic monitoring and control for increate performance by PLC.

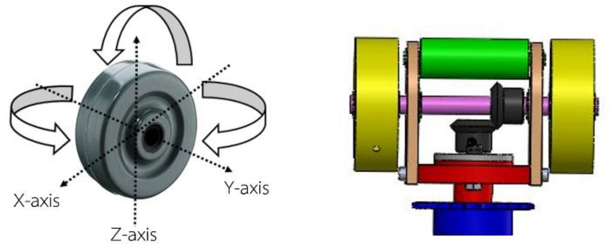
This paper focus to improve the position performance of the directional wheel conveyor by the fuzzy logic controller to control the position direction motor for tracking angle position in directional wheel conveyor prototype. The online input optimal gain and calculation is applied to determine a suitable gains controller for a different setpoint target. The prototype implements PLC and SCADA. The paper proposes a real-time automatic determine output from the fuzzy logic controller for a suitable target value.

II. System of Directional Wheel CONVEYOR

The directional wheel conveyor system consists of mechanical structure, sensors, electrical driving, power transmissions and controller. The contribution of this work is to determine the output of controller from the error of several target angle positions of conveyor. The inertia is assuming and design by solid work. Step to design and develop the real-time control directional wheel conveyor can be present; In the first part, develop a mechanical structure for support object size scale and calculation parameter torque, mechanic movement, transmission mechanism. The second, design instrumentation of positioning can apply the specification to determine the power rate control system. The last part installs the algorithm and determines the optimal parameter value is used to control the plant.

A. Mechanical Structure

In this work, 60-mm diameter rubber wheels were designed to rotate around the Y and Z-axis as shown in Fig. 1 (a), where the rotation of the Z-axis had the range between 0 and 180 degrees. In order to transfer the object in the specific direction, the driven wheel is installed as the module which the direction in Z-axis can be adjusted by applying the position control. CAD design of directional wheel module for the conveyor is shown in Fig. 1 (b). Fig. 2 illustrates the parts assembly of a single module and all mechanical components are listed in Table I. The directional wheel system consists of two main parts: speed (represented in red color) and directional (represented in blue color).



(a) (b)

Figure 1. (a) Directional wheel; (b) CAD design of the directional wheel module.

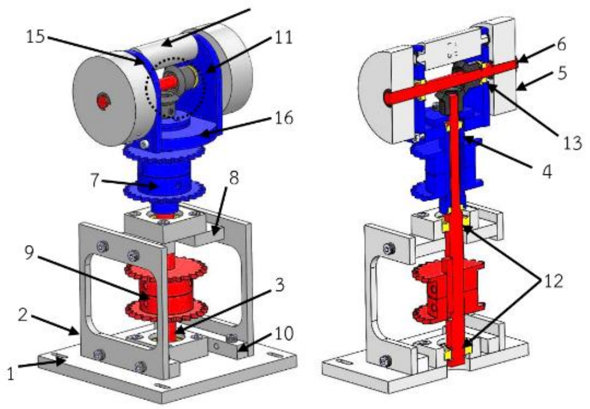


Figure 2. Part of the directional wheel module

TABLE I. Part of Directional Wheel Module

No.	Part name	No.	Part name
1	Base Plate	9	SP-Sprocket
2	Plate Side	10	Bar
3	SP-Shaft	11	Bevel Gear
4	DR-Shaft	12	Bearing A
5	Wheel	13	Bearing B
6	FH-Wheel	14	WH-Shaft
7	DR-Sprocket	15	Plate Side Wheel
8	Support Plate	16	Plate DR-Shaft

Fig. 3 shows the cross section of the mechanical system in order to describe the power transmission among the directional wheel modules. To drive a wheel, the motor provides the driven torque to the SP-shaft (No.3) through Sprocket-1A chain plate of module 1. Both Sprocket-1A and Sprocket-1B were fixed on the same shaft. The Sprocket-1B was chained to the Sprocket-2B which was the next module. By using a single driven motor, all SP-shaft of each module is able to move simultaneously then the wheel was installed on the supporter and was driven through bevel gears.

Fig. 4 shows the transmission of the directional wheel conveyor system can convert rotation from the chain and directional unit. Therefore, the number of tooth and chain joints (x) might be determining. The number of chain joints is calculated from (1).

$$x = \frac{2C}{p} + \frac{Z+z}{2} + \left(\frac{Z-z}{2p}\right)^2 \frac{p}{C} \quad (1)$$

where C is the distance of the center of shaft to shaft.
p is the pitch of the chain plate
Z is the number of cog input shaft drive chain
z is the number of cog output shaft drive chain

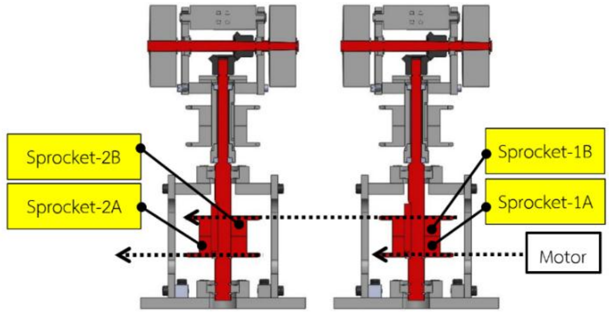


Figure 3. Directional wheel transmission system

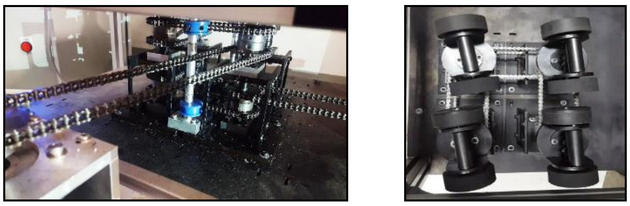


Figure 4. Overview of transmission system

Fig. 5 (a) shows the diagram of power transmission among modules to control the directional conveyor systems as shown in Fig. 5 (b). There are required two actuators to produce torque and speed: M1 is the motor for driven wheels and M2 is the motor to adjust the direction. Both of them were installed at the main base plate of the prototypes so that the produced torque motor is directly applied to the load. The number of directional wheel modules can be increased and controlled by only two motors.

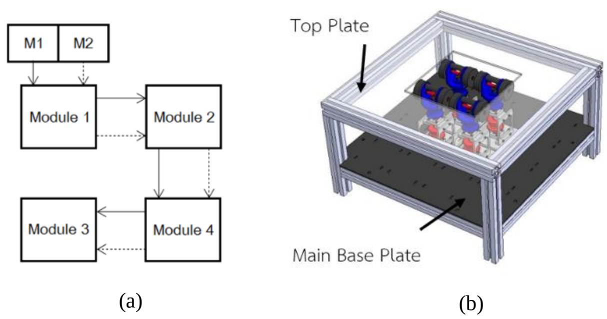


Figure 5. (a) Transmission of multiple modules, (b) CAD design of directional wheel conveyor systems

To select the proper actuator for driven wheels, it can be obtained from the force of directional wheel system which is related to the friction of wheel as shown in (2), where μ is the friction coefficient which is equal to 0.7 for rubber tire on dry load and N is the normal force to the wheel.

$$f = \mu N \quad (2)$$

A force that acts on a moment directional wheel, and is used to cause rotational motion is called torque, T. The amount of torque required to drive an angular acceleration is generally as (3), where r is the wheel radius.

$$T = fr \quad (3)$$

Then, the power of motor can be calculated as (4)

$$P = T\omega \quad (4)$$

B. Servo Motor Drive System

In this research, the controller of directional wheel was designed and implemented in PLC. In order to adjust the wheel angle, the current angular position was measured by an encoder sensor, then PLC generated a servo motor command in high-speed pulse output or other type of signal. Fig. 6 shows the block diagram of position control for directional wheel module where $G(s)$ is the mathematical model of motor, 1/s is integration in Laplace domain.

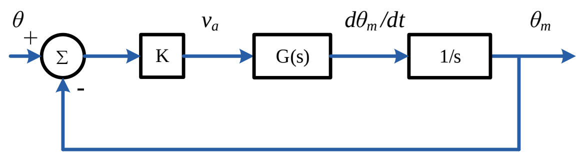


Figure 6. Block diagram of position control for directional wheel module.

Let's define K_t and i_a as the torque constant of motor and armature current, respectively.

$$T = K_t . i_a \quad (5)$$

Refer to (4) the required power motor is greater than 294.25 W, in order to be capable driven all wheels with pay load 1 kg and maximum speed is 2 m/s. Thus, AC servo motor, COOL MUSCLE (C-type) as shown in Fig. 7 was chosen to control the movement of the conveyor with the wheel. Its driver case receives ASCII-code command that be provided by PLC.

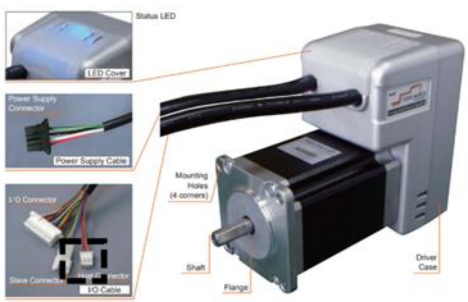


Figure 7. AC servo motor connection

Fig. 8 shows the directional wheel conveyor mechanism and control system. A vision sensor was installed on the top of the directional wheel conveyors to detect the orientation of object. Then the position command is sent from PLC working with SCADA for control and data acquisition. Graphical user interface (GUI) developed by CX-Supervisor software is used to operate overall system by remoting command and parameters in PLC memory. The set point position and feedback angular position can be set and monitor by GUI.

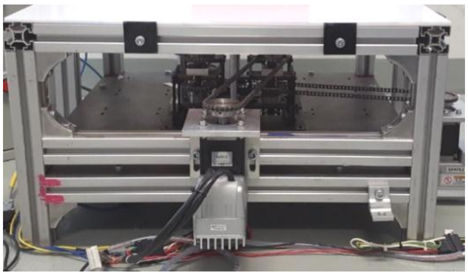


Figure 8. Hardware configuration of directional wheel conveyor

C. *System Achitecture of Directional Wheel Conveyor systems*

The directional wheel conveyor system consists of CP1L–OMRON PLC, SCADA monitoring, two AC Servo motors and camera. The wiring diagram of all components is shown in Fig. 9. The developed systems focus on the orientation tracking of object on the conveyor by image processing and sending the position command to AC servo motors. Firstly, the image from Logitech camera is captured and processed to find the position and orientation of object by using MATLAB Simulink as shown in Fig.10 and OPC Toolbox. PLC CP1L-OMRON gets the set point position via USB cable, then calculate the position command as the control law and send to AC servo motors via RS232 communication.

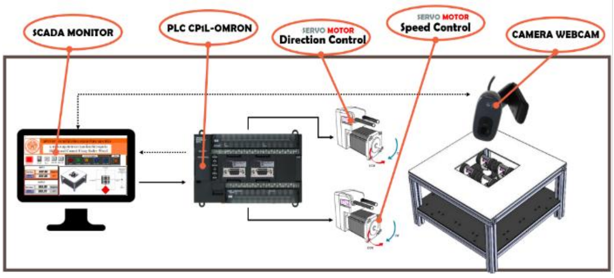


Figure 9. Circuit diagram of directional wheel conveyor.

Figure 10. Camera operating program with MATLAB.

PLC processor based on OMRON is used as the controller to calculate and control direction angle. PLC can program by structure text (ST) and function block diagram (FB). Fig. 11 shows the example of PLC programing PLC for directional wheel conveyor.

System operation procedures

1. SCADA screen: The user enters the workpiece trajectory data and checks the resulting result through the SCADA screen.

2. PLC: The PLC receives a signal from the SCADA to process and send a control signal to the next part. The COOL MUSCLE motor drives to adjust the direction and speed for the directional conveyor movement.

3. Drive unit: It is a castor driven unit that moves the conveyor to the desired target path in range 0 - 180 degrees from the reference point.

4. Camera: It installs to detect the movement of objects on the conveyor. Feedback of position the conveyor along the desired path by image processing and adjust signal for control conveyor the signal obtained from the camera. To be a feedback signal in the system for the PLC. The position and orientation of object is measured by image processing as shown Fig. 12 and communicate with the PLC for close-loop control.

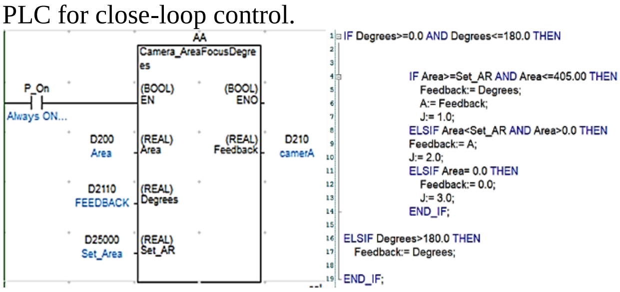


Figure 11. PLC programming of close loop control position

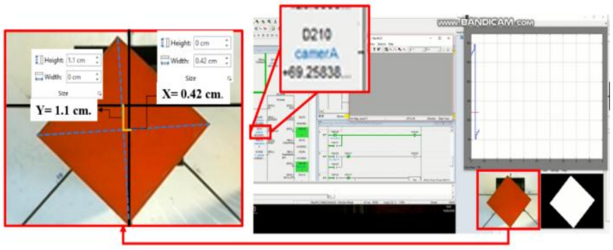


Figure 12. Measure the position of objects by image processing and communicate with the PLC for close loop control.

To evaluate the conveyor controller, there are three condition of experiment setup. Refer to Fig. 13, the set point angular position was set at 30, 60, 90, 120 and 150 degrees. The speed of the objective that move from point A (starting point) to the sorting point which the orientation of object can be adjusted. The set point speed was set at 0.2 m/s, 0.27 m/s and 0.33 m/s, respectively. Lastly, the weight and size of object was varied as small, medium and large.

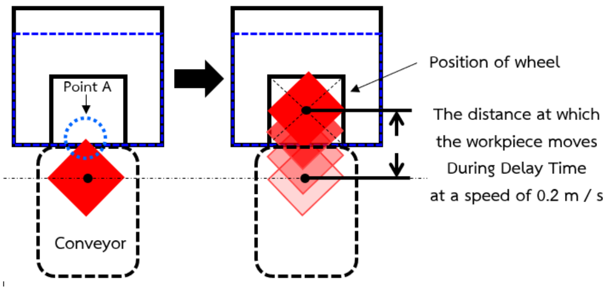


Figure 13. Experimental setup of work objective sizes and speed.

III. Controller Design

The main objective of controller design is to improve the performance of directional conveyor control wheel by adjusting the orientation angle of driven motor. The difference between the various target angle position and orientation sensed by camera was used to calculate the position command.

A. Proportional Integral Derivative Controller

The proportional integral derivative controller has been popularly used in control engineering because it is stable and has a simple structure [22]-[24]. PID controller was applied to control the directional angle using the sum of proportional integral and derivative value of tracking error. The discretized PID controller can be expressed as (6) – (9). These equations can be implemented by PLC programming.

$$G_{pid} = K_p + K_i \frac{Ts}{1-z^{-1}} + K_d \frac{1-z^{-1}}{Ts} \quad (6)$$

$$G_p = K_c e(kT), \quad G_i = u(k\text{-}1) \quad (7)$$

$$G_i = u(k\text{-}1) + \left(\frac{K_c Ts}{2Ti}\right)[e(kT) + e(kT\text{-}T) \quad (8)$$

$$G_d = \left(\frac{K_c Ts}{2Ti}\right)[e(kT) + e(kT\text{-}T)] \quad (9)$$

B. Ziegler-Nicole Tuning PID

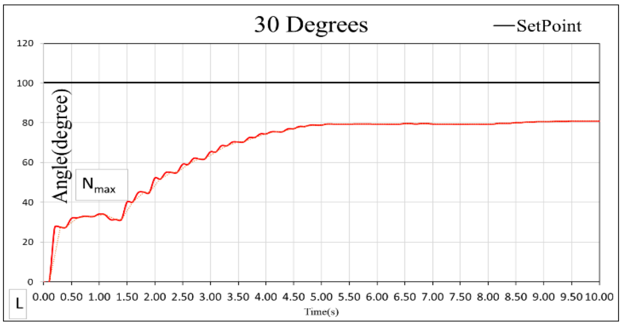


Figure 14. Determination of Ziegler-Nicoles at direction angle 30 degree.

Ziegler-Nicoles method is used to determine to PID controller gains: K_p, K_i, and K_d based on experimental data. It does not require mathematical modeling, thus this method is widely used to tune the gains and apply in PID controller algorithm [25], [26]. Open-loop Ziegler-Nicole's tuning method begins with injecting the step input to open-loop system. The step response as shown Fig. 14 represents the characteristic of the system plant and is used to determine K_c, T_d and T_{value} in (10), (11) and (12), respectively. The PID parameter can be calculates by equation as:

$$K_c = \frac{1.20}{L \times N_{max}} \quad (10)$$

$$T_d = 2 \times L \quad (11)$$

$$T_{value} = \frac{L}{2} \quad (12)$$

Table II lists tuned PID controller gains by using Ziegler-Nichols method with the different step input. The result shows that the optimal gain was different. The target angle is larger; the proportional gain is smaller.

TABLE II. Gain PID Controller Using Ziegler and Nicole

No.	Target angle (degree)	K_p	K_i	K_d
1	30	6.72	1.00	0.25
2	60	4.56	1.00	0.26
3	90	3.30	0.40	0.10
4	120	1.80	0.40	0.10
5	150	1.20	1.50	0.38
6	180	1.00	0.50	0.52

C. Fuzzy Logic Controller

For the fuzzy logic controller design, the error value caused by the input-output (Setpoint - Feedback) is the input of the controller. A fuzzy logic controller has to determine all the time that the work object moves on the castor module.

TABLE III. Range of Input Function

No	Input	Range	Output
1	VL	[0 0 32]	0
2	LL	[0 22.5 41]	22.5
3	LB	[12 45 77]	45
4	L	[45 67.5 90]	67.5
5	M	[57 90 122]	90
6	H	[90 112.5 135]	112.5
7	HB	[102.5 135.5 167.5]	135
8	LHB	[135 157.5 180]	157.5
9	VH	[147 180 180]	180

To bring the results of the verification process in the fuzzy system to real-world values. The result of defuzzification is to control the motor in order to adjust the direction of motion. The range of input which is between 0 – 180 degrees is divided into nine cases. The triangle function is used to determine the number of values in each range. Table III. present the range of input of the Fuzzy function.

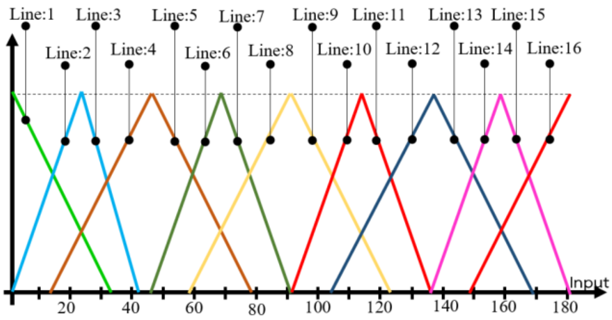


Figure 15. Diagram of fuzzy logic controller.

The next step is to design the membership function from the information in Table III to create equation values in the fuzzy system. (Defuzzification) The first step is to use the data in Table III to create a membership. An example of constructing a triangle is assuming that the function Z = [A B C] where A-B-C is constant when create a triangle as Fig. 15.

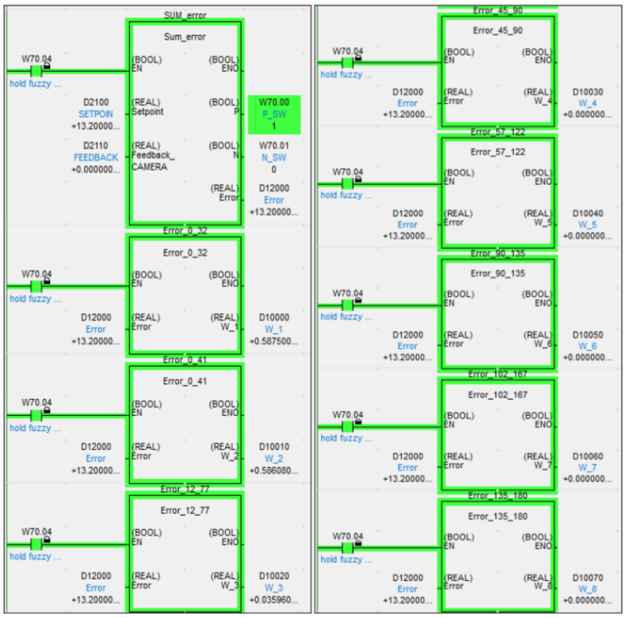


Figure 16. Embedded PLC for calculation fuzzy controller.

Fig. 16 and Fig. 17 illustrate the comparison of results between simulations and calculations from PLC software. The results obtained from the simulation on the MATLAB program was 12.3, which is close to the computational side of 12.225. The output value of the fuzzy logic control is written on the program. The PLC software (CX-Programmer) shows calculating using embedded PLC. The result of embedded PLC is value 13.23 which is similar to the simulation.

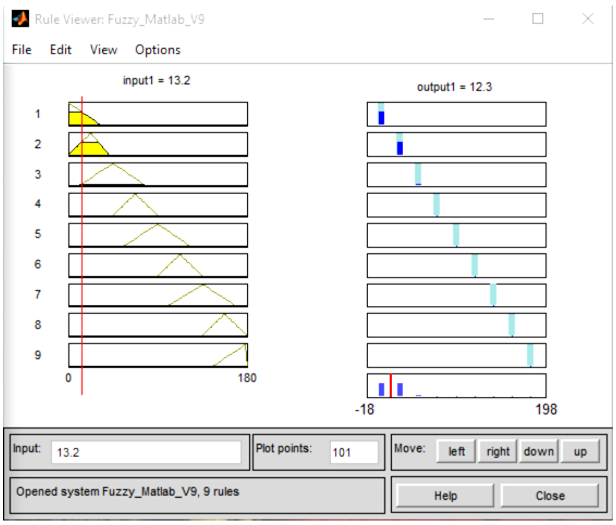


Figure 17. Simulation test fuzzy controller using MATLAB.

IV. Result and Discusston

A. No Load Experiment

To verify the performance of fuzzy logic control in orientation tracking, the first experiment is no-load test by applying an empty box. Fig. 18, Fig. 19 and Fig. 20 show the effectiveness of controller when the speed of wheels was set at 0.2, 0.27 and 0.33 m/s, respectively. The bar graph which has five groups as the target orientation at 30, 60, 90, 120 and 150 degrees represents the average value of steady-state angle measured by the vision sensor. The different size of objects was sent to the module which size S, M and L has the dimension 150×150×150 mm, 200×200×200mm and 250×250×250mm, respectively.

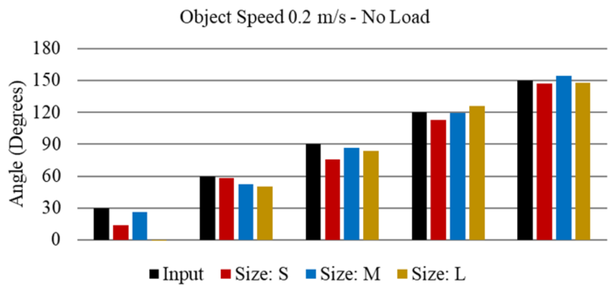


Figure 18. Experimental results without load at 0.2 m/s of each size.

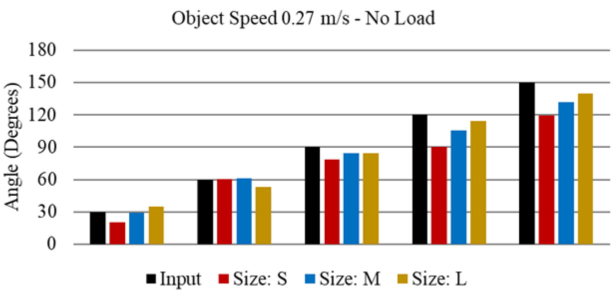


Figure 19. Experimental results without load at 0.27 m/s of each size.

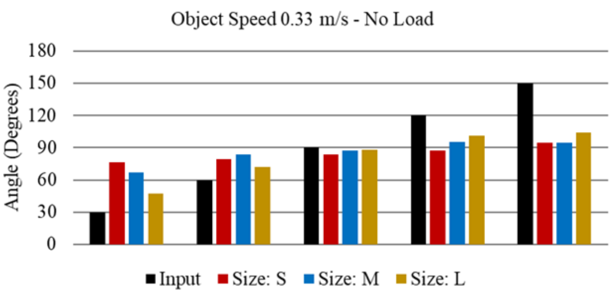


Figure 20. Experimental results without load at 0.33 m/s of each size.

For speed of object at 0.33 m/s, the result shows that the error of angle position is high especially large target set point, due to the limitation of computation for image processing. Thus, the average tracking error and the standard deviation (S.D.) value for no-load experiment are summarized in Table IV. For all target angle, the optimal speed for loading medium-size object is 0.2 m/s, while as the large-size object, the suitable speed is 0.27 m/s.

The result concludes that the size of object is increased, the required feed speed. The reason is that the feature point to detect the position of object is at the corner as shown in Fig. 13. Comparing among size of object, the distance that requires to move is increased for larger size while the distance calculated from wheel speed and delay time for command transmission by PLC.

TABLE IV. AVERAGE ERROR VALUE AND S.D. OF NO-LOAD EXPERIMENT

M-size object										
Target Angle (degree)	30		60		90		120		150	
Speed (m/s)	0.20	0.27	0.20	0.27	0.20	0.27	0.20	0.27	0.20	0.27
Average Error (degree)	3.50	3.83	7.39	5.50	3.28	5.27	3.43	14.71	7.72	17.97
SD	0.79	2.25	2.91	3.88	1.16	1.09	2.59	10.32	8.62	8.47
L-size object										
Target Angle (degree)	30		60		90		120		150	
Speed (m/s)	0.20	0.27	0.20	0.27	0.20	0.27	0.20	0.27	0.20	0.27
Average Error (degree)	22.35	4.83	9.99	6.64	5.97	5.29	5.65	5.60	5.36	10.58
SD	5.36	0.46	2.87	2.04	0.36	0.61	5.99	4.72	2.71	7.12

B. *On Load Experiment*

In this experiment, the standard 1 kg and 2 kg were put inside box, then the experiment was conducted similar to no-load test by set feeding speed at 0.27 m/s. The results of M size and L size-object show in Fig. 21 and Fig. 22, respectively. The average tracking error and the standard deviation (S.D.) value for on load experiment are summarized in Table V. For small-size object, the average error value is increased for the larger set point value.

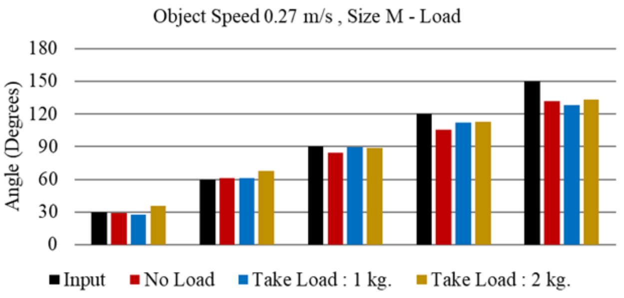


Figure 21. Experiment results with load at 0.27 m/s speed of size M.

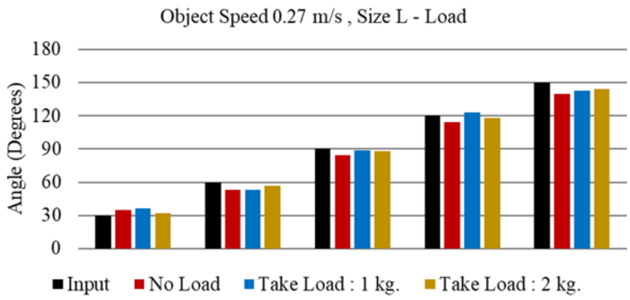


Figure 22. Experiment results with load at 0.27 m / s speed of size L.

TABLE V. AVERAGE ERROR VALUE AND S.D. OF LOAD EXPERIMENT

M-size object										
Target Angle (degree)	30		60		90		120		150	
Load (kg)	1	2	1	2	1	2	1	2	1	2
Average Error (degree)	2.24	5.60	0.95	7.96	0.72	1.42	7.80	7.02	21.8	16.45
SD	2.24	2.34	6.65	3.87	0.26	0.24	5.24	4.23	8.34	2.43
L-size object										
Target Angle (degree)	30		60		90		120		150	
Load (kg)	1	2	1	2	1	2	1	2	1	2
Average Error (degree)	6.19	2.05	6.55	3.13	0.84	2.08	3.22	1.7	7.45	6.12
SD	2.79	5.07	3.43	3.08	0.74	0.87	1.76	4.97	6.92	1.95

C. *Effectiveness of Proposed Controller*

In this experiment, the effectiveness of proposed controller is verified by comparing with open-loop control which PLC sent position command when the object arrived. The result of performance comparison is shown in Fig. 23 by applying set-point 30, 60, 90, 120, and 150 degrees and feeding M-size object with 0.2 m/s. The result shows that Fuzzy logic controller can improve the performance of tracking error. The maximum average error value is 2.25 degree for set-point 90 degree and the minimum value is 0.4 degree for set-point 60 degree.

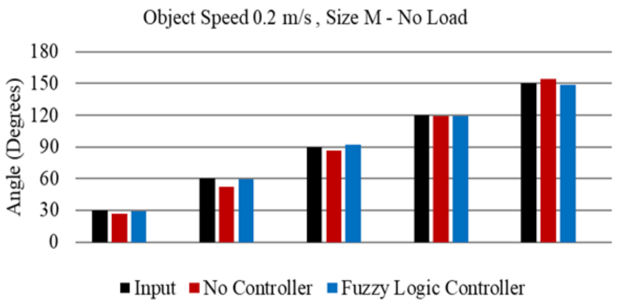


Figure 23. Fuzzy Logic Controller results compared with non-controller experiments at M-No Load work object, speed 0.2 m / s.

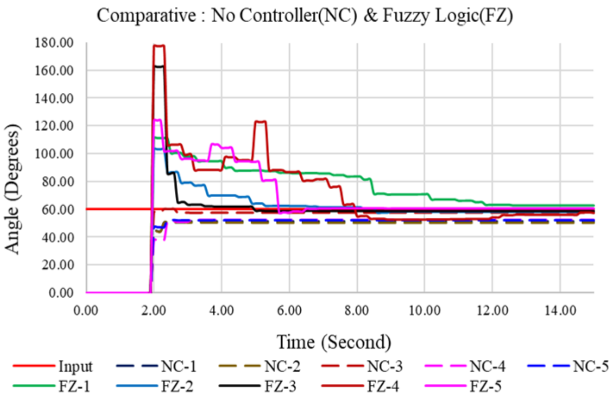


Figure 24. Experimental result of fuzzy logic controller.

To validate the response of Fuzzy logic controller, the step response of set point 60 degree was compared in Fig. 24 which there are five responses for open-loop control and five responses for Fuzzy logic controller. The results show that Fuzzy Logic controller provides the zero steady-state error. However, the open-loop control reached steady-state region faster depending on AC servo controller.

V. Conclusion

This research presents the development of directional wheel conveyor using PLC for real-time orientation control. Mechanical design, control, and Fuzzy logic controller for embedded PLC are reviewed. By using speed and image of the object detected by the camera, the system adapts the orientation of object more accurately. In this paper, Fuzzy logic controllers was proposed and implemented to the system in order to track the orientation of object to the target angle position. Experimental results represent the steady orientation of object after fed into the directional wheel conveyor. The work condition such as size and weight of object, feeding speed and target angular position was also considered. The results show that the main factor affecting the displacement accuracy is the size of the work object. Thus, the size of object should be used to adapt the feeding speed to improve the accuracy in future work.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

SH. conducted the research. SC and CS analyzed the data and approved the final version. The authors were involved in the drafting of drafting of the manuscript and had approved the final version

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