Hybrid Artificial fuzzy-PID adaptive algorithm Design for industrial Conveyor lines speed synchroniser

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Abstract— In this work, an artificial hybrid fuzzy PID control algorithm is successfully designed and tested, for employing in master-slave motion synchronizing control technique, intended for industrial conveyor lines speed synchroniser , but also can be applied where actions require synchronization with conveyor system motions including in industry, production processes, business and facilities, the algorithm is designed to get a good balance amongst desired system performance and system parameter variations. The overall conveyer system mathematical and simulation models were built by integrating the derived submodels of all subsystems and components including; the main actuator, loads, control unit with algorithm and sensor. MATALB/Simulink environment was used to develop the design; test the submodels and overall system model. Testing the overall system design by subjecting it to different scenarios, including to achieve the needed speed of one conveyer with desired performance, also to achieve and synchronize this speed by the other conveyer, show that the algorithm can result in synchronized motion with fast acceptable response speed, short setting time, and minimum both error and overshoot.

Keywords: Conveyer line, speed control, speed synchronization, master-slave control.

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1. INTRODUCTION

In many production processes, business and facilities, a rising number of actions require synchronization with conveyor system motions. To ensure achieving synchronized motion with desired high levels of speed and precision, complex control solutions are required. A conveyor system also called a belt conveyor or simply a conveyor is mechanical machinery that is often spread out over a distance and usually used to transport bulk materials, unit items, goods or objects from one place to the other, making it possible to transport, receive, and ship items with desired speed, efficiency and reduced to minimal labor expense. The basic construction of a conveyor system, can be considered consisting of a stretched between two pulleys belt of fabric, that is also, in a closed loop, wrapped around the two pulleys which allows the belt to rotate around them. With one, operating under power, drive pulley and other idle pulley. Because of its remarkable utility and versatility, the conveyor lines are utilized in almost every type of business and facility. Application of a Conveyor system involves an elementary speed control algorithm wherein the drive module simply regulates the operating speed at a set point that may be adjusted from time to time [1][2]. In case multiple conveyor lines are employed, the lack of synchronized speeds between different conveyor lines, as well as, other process machines, results in various problems, Conveyor lines speed synchronisers are employed to prevent many of these problems. Conveyor lines speed synchronizers are very important component of production lines. The speed synchronisers are designed to synchronize different conveyor lines speed with the speed of both other conveyer lines and with the action of all the process machines within the production network [2]. The different speeds are synchronized to reduce to zero the differential speed error between the different actions. The speeds Synchronization process is achieved by designing a complex control algorithm that, at every occasion during the system operation by tracking the accurate reference signal and eliminating disturbances, will properly adjust and allocate the appropriate control voltage (or current) signal value to drive the conveyer system to achieve the desired Synchronized speed. In this work, artificial intelligence is employed to suggest hybrid artificial fuzzy-PID adaptive algorithm design that can be applied for industrial conveyor lines both speed control and Conveyor lines speed synchronisers. This work is written as follows; in Section 2, system Methodology is presented. In section 3, Subsystems design and modeling, are presented, including the hybrid artificial fuzzy PID algorithm. In section 4; subsystems and overall System simulation, testing and evaluation are presented, finally, Conclusions and future work

2. SYSTEM METHODOLOGY AND WORKING PRINCIPLE.

In this work a control algorithm is designed to achieve a synchronized speed, for actions requiring synchronization with conveyor system motions including in industry, production processes, business and facilities.. synchronized speed of two conveyer lines is where the second conveyor line turns 15 degrees when the first conveyor line turns 15 degrees, meanwhile, achieving similar speed of two conveyer lines, is when two motors with controllers and drivers (e. g. adjustable speed drive) are set to the same control value, to run both lines at the same speed, but due to slip, there will be a few RPM off, a drift over time. There are three applied classes of control techniques applied for achieving synchronized motion; *(a)* Master-slave motion control, *(b)* Synchronous master motion control, also called parallel synchronous control, and *(c)* Relative dynamic stiffness motion control. [3][4]. The speed of two electric motors is synchronized by sending simultaneously the same control signal to both electric motors in synchronous master motion control technique, shown in Figure 1(a). in this technique, the motors speed are controlled independently, without taking in consideration the speed of the other motor, therefore an accurate synchronous motions may not be guaranteed. To overcome this weakness, the master-slave motion control technique shown in Figure 1(b) is developed. This technique operates in a cascade manner, where a slave electric motor follows the master one. In Figure 1(c) is directed the speed deviation coupling motion control technique. The master-slave motion synchronizing control technique is applied in this work to synchronize the speed of two conveyer lines and actions. The working principle of technique is developed based on utilizing microcontroller as control unit and encoder as electric motors' shaft position sensor, such that one conveyer line (the slave) will follow the other conveyer line (the master) according to position (not speed), so their speeds will be synchronized according to shaft position read by

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the encoder with less than a degree of rotation. In this setup, the position difference between the two encoders is employed as the input error signal to the control algorithm, based on which an output analog control signal is generated to control the speed of the slave conveyor in term of shaft position, such that it will match the position of the master conveyer line. Moreover, in this work, Hybrid Artificial fuzzy-PID algorithm is designed to control the speed synchronization process of both conveyer lines.

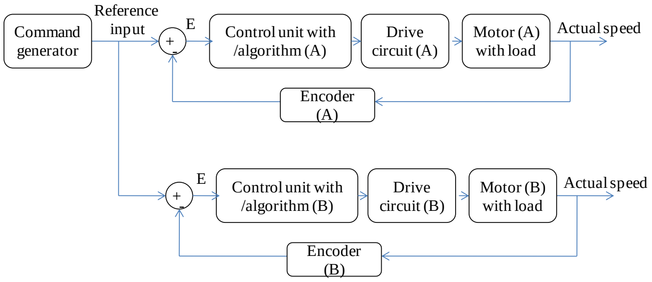

Fig. 1(a) the parallel synchronous master motion control technique,

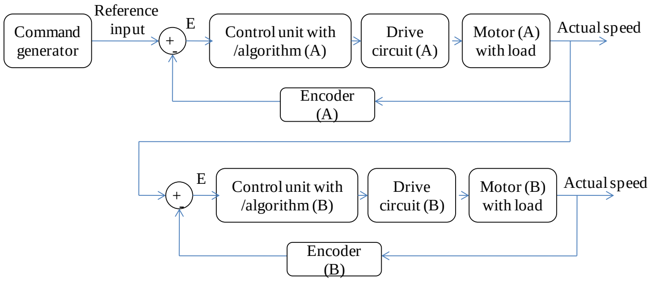

Fig. 1(b) the master-slave motion control technique

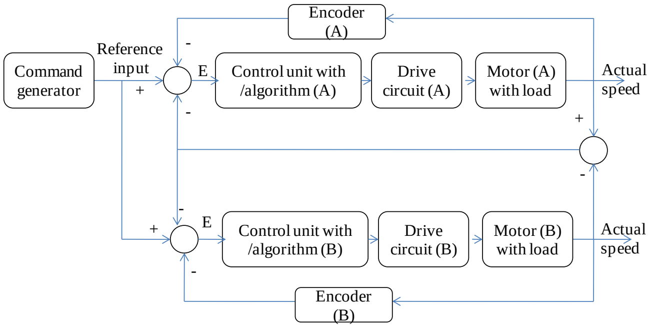

Fig. 1(c) speed deviation coupling motion control technique.

3. SUBSYSTEMS AND COMPONENTS DESIGN AND MODELING

To validate the suggested algorithm design, the system consists of two conveyer lines utilizing two with similar parameters geared DC motors, a microcontroller as speed synchronizer control unit, two drive circuits, and two encoders as position sensors. to represent the dynamic behavior of the whole system, In this section each of these subsystems and components is designed, mathematically represented, finally an overall system model is developed by integrating all subsystems in one.

3.1 Conveyer line design and modeling

So as to represent the dynamic performance of the conveyor line speed synchronizer, control algorithm and sensors it is required to derive the mathematical model of motor drive-conveyor system [5].

In literature, modeling the dynamics of conveyor line, from different points of view and applying different methodologies, can be found in different sources including the following; [1] [6-12].

Synchronizing speeds of different conveyer lines can be simplified to synchronizing the speed of electric motors used to drive the pulleys in these lines. In this work, the mathematical model of a single conveyer line developed in [1] is used and further modified to develop the two conveyers system, for further synchronizing there speeds, test and evaluate it behavior.

DC electric motor is used to drive the single line belt conveyer system and for driving the inertial load. The input to the electric motor the appropriate adjusted control input voltage $V_{in}(t)$ signal value controlled by the drive circuit module to achieve the desired speed. The output is the motor's shaft angular speed $\omega(t)$. This angular speed is transmitted to the directly coupled conveyer's drive pulley or roller which allows the belt to rotate around it. This angular motion is converted into liner belt's motion.

The mathematical model of DC electric motor can be found in various sources in literature including in [13-18]. The DC motor is a case of electromechanical systems with multiple components electrical and mechanical [18], the electric motor mechanical and electrical aspects are separately represented mathematically, then the conveyer belt torque design aspect are derived and represented, finally an overall integrated open loop transfer function model of all conveyer line components is derived and presented.

The electrical part of the DC motor can be mathematically represented Referring to figure 2(a), and applying Kirchhoff law, as given by Eq.(1), all voltages sum around a loop is equal to zero. Substituting in Eq.(1), the corresponding voltages expressions through resistor and inductor, as well as, the generated back *emf* voltage, the electrical part of the DC motor can be represented mathematically by Eq.(2).

Representing the motor mechanical aspects; a constant level of torque is essential to drive the conveyer system nonetheless the operating speed [12]. Applying energy saving, the overall resulting torque on motor shaft, as given by Eq.(3), must equal zero. The torque developed by the motor, $t(t)$ is proportional to the armature current, $i_a(t)$ and torque constant, K_t as given by Eq.(4). The appropriate torque to rotational acceleration of the rotor, T'_ω, is given By Eq.(5), where J_{tot} is the total inertia of both the motor rotor and the conveyor system. The torque T_ω produced as a result of rotor velocity is given by Eq.(6), where: K_f is the viscous damping friction associated with the rotating members of the motor [14][15].

Now, Substituting Eqs.(4), (5) and (6) into (3), results in Eq.(7). rearranging Eq.(2) in terms of induced current and rearranging Eq.(7) in term of resulting angular speed rate, result in Eqs.(8) and (9)

$$V_{in} - V_{R_a} + V_{L_a} + V_{emf} = 0 \tag{1}$$

$$V_{in}(t) = R_a i(t) + L_a \frac{di(t)}{dt} + K_b \omega(t) \tag{2}$$

$$t(t) - T'_\omega - T_\omega - T_c = 0 \tag{3}$$

$$t(t) = K_t * i_a(t) \tag{4}$$

$$T'_\omega = J_{tot} \frac{d\omega(t)}{dt} \tag{5}$$

$$T_\omega = K_f \omega(t) \tag{6}$$

$$K_t * i_a(t) - J_{tot} \frac{d\omega(t)}{dt} - K_f \omega(t) - T_c = 0 \tag{7}$$

$$\frac{di(t)}{dt} = -\frac{1}{L_a}\left[R_a i(t) + K_b \omega(t) - V_{in}(t)\right] \tag{8}$$

$$\frac{d\omega(t)}{dt} = \frac{1}{J_{tot}}\left[K_t\ i_a(t) - K_f\,\omega(t) + T_c\right] \tag{9}$$

Based on these derived equations , the nominal model shown in Figure 2(b) was built. it is the belt conveyor system model including motor electromechanical components and torque is built.

Deriving the torque T_c: referring to figure 2(c), the conveyor line is assumed directly coupled to the motor pulley or roller. As given by Eq.(10), the overall total transported Mass by the conveyor line system is the mass of belt and the mass of individual items being transported.

$$T_{tot} = M_{belt} + M_1 + M_2 + M_3 \tag{10}$$

The conveyer linear acceleration can be expressed in terms of angular measures and acceleration, as given by Eq.(11), where: F_e is the effective belt tension, α_m is the angular acceleration of drive pulley coupled to the motor shaft.

Based on this, The required force to accelerate the total mass M_{tot} is related to the torque around the motor shaft as given by Eq.(12):

$$F_e = \frac{1}{2}D_m M_{tot}\alpha_M \tag{11}$$

$$\begin{aligned} T_{M_{tot}} &= \frac{1}{4}D_m^2 M_{tot}\alpha_M \\ J_{M_{tot}} &= \frac{1}{4}D_m^2 M_{tot}\left[\frac{D_m}{D_1}\right]^2 \end{aligned} \tag{12}$$

Referring to figure 2(c), the overall total mass inertia of the conveyer system about the drive *shaft1* is given By Eq.(13). The torque generated is related to mass inertia, and acceleration by Eq.(14). Based on this, and substituting values, the produced toque by the conveyor system is given by Eq.(15), and the total produced inertia is given by Eq.(16)

$$\begin{aligned} J_{convey} &= J_{mR} + J_{IR} + J_{rR} + J_{M_T} \\ J_{convey} &= J_m\left[\frac{D_m}{D_1}\right]^2 + J_I\left[\frac{D_m}{D_1}\right]^2 + nJ_R\left[\frac{D_m}{D_i}\right]^2 + \frac{1}{4}D_m^2 M_{tot}\left[\frac{D_m}{D_1}\right]^2 \\ J_{convey} &= \left[\frac{D_m}{D_1}\right]^2\left[J_m + J_I + nJ_R\left[\frac{D_1}{D_i}\right]^2 + \frac{1}{4}D_m^2 M_{tot}\right] \end{aligned} \tag{13}$$

$$T = J_{convey} * \alpha_m \tag{14}$$

$$T_c = \left[J_m + J_I + nJ_R\left[\frac{D_1}{D_i}\right]^2 + \frac{1}{4}D_m^2 M_{tot}\right]\left(\frac{D_m}{D_1}\right)^2 \alpha_m + \frac{1}{2}\mu M_T g D_m \tag{15}$$

$$J_{total} = J_{convey} + J_R \tag{16}$$

The torque and inertia of both the system are calculated by derived equations and the DC motor , also by substituting the parameters listed in Table 1, are as shown in Eq.(17)

$$\begin{aligned} J_{conv} &= 1.760 \quad kgm^2 \\ T_c &= \left(1.760\ \alpha_m + 9.6825\right) \quad Nm \\ J_{total} &= J_{conv} + J_R = 1.760 + 1.8*10^{-2} = 1.7767 \quad kgm^2 \end{aligned} \tag{17}$$

The linear velocity of the conveyer belt is associated with the angular speed of motor' shaft and pulley diameter as given by Eq.(18)

$$v_{belt}(t) = \frac{1}{2}\omega(t)D_m \quad \Rightarrow \quad \omega(t) = \frac{2*v_{belt}(t)}{D_m} \tag{18}$$

Substituting the calculated, derived values and expressions in Eqs.(8) and (9), to have the form given by Eq.(19) and (20). Taking Laplace transform and rearranging, equation will have the form given by Eqs.(21) and (22). Deriving the transfer function relating the input voltage and conveyer output linear speed is done by rearranging and relating both equations in term of current. The transfer function is given by Eq.(23) .

Substituting parameters given in table 1, the transfer function given by Eq.(24)

Based on all derived equations, the simulink model of the belt onveyor system model with all components are developed in next section.

$$\frac{di(t)}{dt} = -\frac{R_a}{L_a}i(t) - \frac{2K_b}{L_a D_m}v_{belt}(t) - \frac{1}{L_a}V_{in}(t) \tag{19}$$

$$\begin{aligned} \frac{dv_{belt}(t)}{dt}\frac{2}{D_m} &= \frac{K_t}{J_{tot}}i_a(t) - \frac{2K_b}{J_{tot}D_m}v_{belt}(t) - \frac{\left(1.760\ \alpha_m + 9.6825\right)}{J_{tot}} \\ \frac{dv_{belt}(t)}{dt} &= \frac{K_t}{8J_{tot}}i_a(t) - \frac{K_b}{4J_{tot}D_m}V_{belt}(t) - \frac{9.6825}{8J_{tot}} \end{aligned} \tag{20}$$

$$I(s) = \frac{-2K_b v_{belt}(t) + D_m V_{in}(s)}{D_m(L_a s + R_a)} \tag{21}$$

$$V_{belt}(s) = \frac{K_t D_m I(s) - \dfrac{10D_m}{s}}{8J_{tot}s + 2K_b} \tag{22}$$

$$\frac{v_{belt}(t)}{V_{in}(t)} = \frac{\dfrac{K_t s - 10}{8L_a J_{tot}}}{s^3 + \left[\dfrac{2L_a K_b + 8R_a J_{tot} D_m}{8L_a J_{tot} D_m}\right]s^2 + 2\left[\dfrac{R_a K_b + K_t K_b D_m}{8L_a J_{tot} D_m}\right]s + \dfrac{5K_b}{2L_a J_{tot}}} \tag{23}$$

$$\frac{v_{belt}(t)}{V_{in}(t)} = \frac{0.1181s - 41.74}{s^3 + 29.63s^2 + 1.217s - 2.326} \tag{24}$$

Based on these derived equations, the shown in Figure 2(b) is built. it is the nominal model of the belt conveyor system model including motor electromechanical components and torque.

In [6] authors developed a nonlinear conveyor belt system considering the nonlinear friction, backlash and other effects on the system, the derived transfer function for that model is given by Eq. (25), the blockdiagram representing conveyer system is shown in Figure 2(d) the hybrid control algorithm, the will be developed in next section, will be also tested on controlling this conveyor belt system model

$$G(t) = \frac{0.09625s^2 + 0.3396s + 0.09806}{0.4208s^3 + 0.4608s^2 + 0.1659s + 0.01968} \tag{25}$$

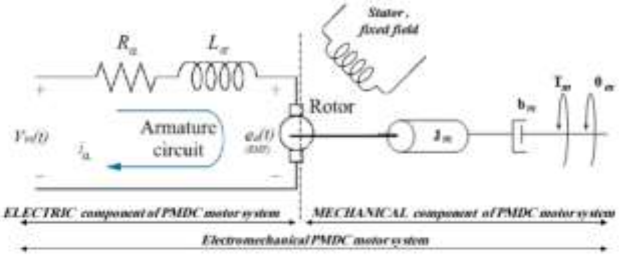

Fig. 2(a) Schematic illustration of the DC motor's electromechanical sections[18]

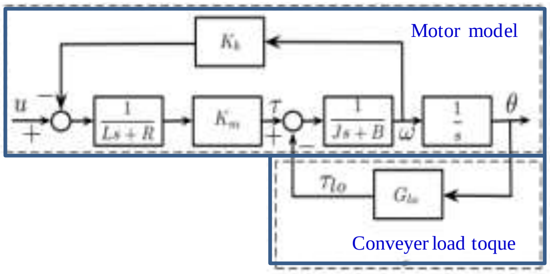

Fig. 2(b) The nominal model of the belt conveyor system [12]

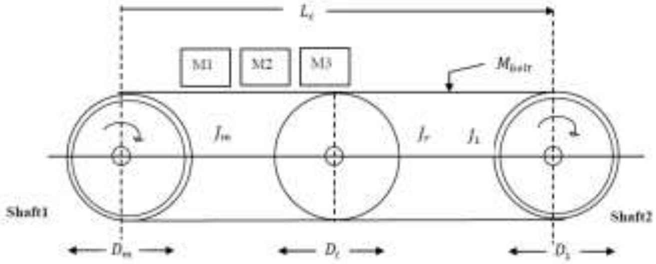

Fig. 2(c) Drawing of the belt conveyor for DC motor torque analysis [1]

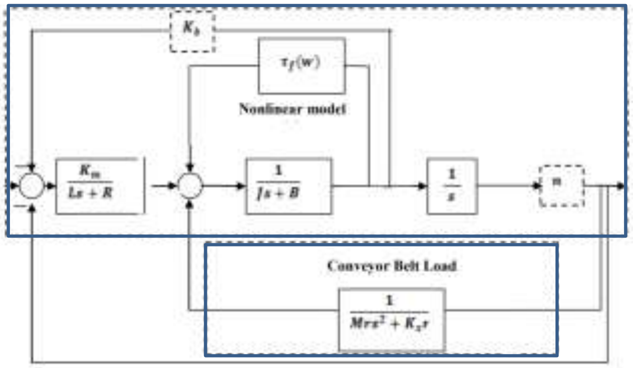

Fig. 2(d) blockdiagram representing conveyer system with load and nonlinearity

TABLE 1:
System parameters [1]

DC motor parameters		
Parameters	Values	Units
Armature Resistance (R_a)	0.50	Ω
Armature Coil Inductance (L_a)	1.69x10-2	H
Armature Torque Constant (K_t)	2.83x10-2	Nm/A
Back emf constant (K_b)	2.83x10-2	Vs/rad
Viscous Damping coefficient (K_f)	5.8x10-2	Kgm2/s
Motor Armature Inertia (J_a)	1.06x10-2	Kgm2
Belt conveyor parameters		
Conveyor Length (L_C)	30	M
Conveyor width (b)	0.6	M
Drive Drum Diameter (D_m)	0.2	M
Driven Drum Diameter (D_1)	0.195	M
Idler Diameter (D_i)	0.1	M
Number of idlers (n)	15	-
Idler spacing (s)	2	M
Mass of transported item, empty/full (M_1, M_2, …)	3.5	Kg
Density of material (Au) (ρ)	2702	Kg/m^3
Coefficient of friction between belt, pulleys and idlers (μ)	0.35	-
Belt thickness (t)	0.025	M
Mass inertia of drive drum (J_m)	0.2547	Kgm^2
Mass inertia of driven drum (J_1)	0.2302	Kgm^2
Mass inertia of idler (J_r)	0.0159	Kgm^2
Length of drums and idlers (L)	0.6	M
Mass of belt (M_{belt})	7.2(0.24kg)	Kg
Density of belt material (ρ_1) (Rubber)	480	Kg/m^3
Acceleration due to gravity (g)	9.81	m/s^2

3.2 Hybrid fuzzy-PID adaptive control algorithm modeling and design

To overcome the difficulties in controlling the dynamics of conveyer system, resulting from the existing in the conveyer system, nonlinearities and system parameter variations; sudden changes in speeds and loads, the suggested control algorithm to control and synchronise the speed is the hybrid fuzzy PID algorithm, the overall control algorithm consists of two integrated algorithms; artificial fuzzy algorithm to assign the gains of PID algorithm, and a separate PID control algorithm, that automatically switched on, when system dynamics changes intensively and suddenly, or to reduce the error in resulted speed to minimum values.

This hybrid fuzzy PID control algorithms can be categorized into the following three categories: *(a)* the Fuzzy-PID gains scheduling algorithm with architecture shown Figure 3(a). In this algorithm, the fuzzy algorithm is used to automatically tune the gains of the conventional PID controller on-line. In this hybrid algorithm type, the PID control algorithm is generating the control signal to control the physical system. *(b)* The hybrid fuzzy-PID controller with architecture shown Figure 3(b). In this algorithm depending on the distance to desired output value and /or system response, one of two control algorithms is selected to generate control signal. *(c)* Direct action Fuzzy PID control, this type is also classified, based on the number of the input variables into the following types of Direct action fuzzy PID controllers; single input, two inputs, and three inputs [19]. Furthermore, the two inputs is further classified into the next types; fuzzy-PD, fuzzy-PI, fuzzy-adaptive algorithms.

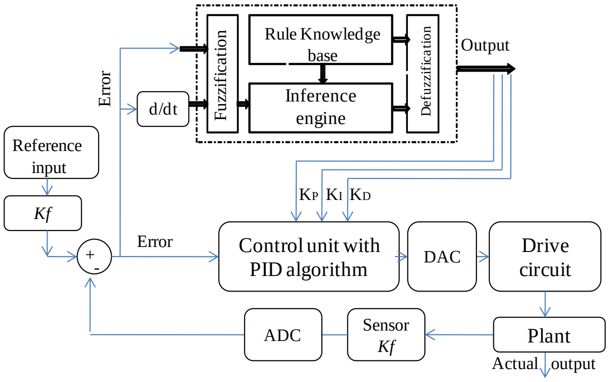

Fig. 3(a) the architecture of Fuzzy-PID gains scheduling algorithm

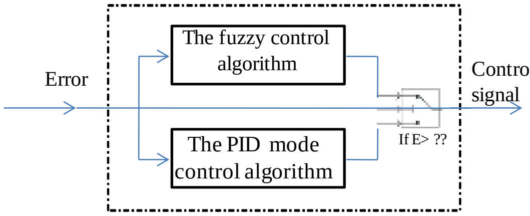

Fig. 3(b) The architecture of hybrid fuzzy-PID controller

The hybrid fuzzy PID algorithms is selected for controlling and synchronizing the speed of the conveyer and get a good balance amongst desired system performance and conveyer system parameter changes. The algorithm is developed by integrating two forms of hybrid artificial fuzzy-PID control algorithm, the first and second types. This algorithm is developed such that, depending on both the error value and system response, one of two control algorithm is selected to generate control signal.

The architecture of the suggested hybrid control algorithm is shown in Figure 3(c). The overall conveyer system with components layout are shown in figure 3(d). The flowchart representation of the algorithm design and calculation are shown in figure 3(e).

The Hybrid artificial fuzzy PID gains scheduling algorithm consists of two integrated algorithms; the artificial fuzzy algorithm and the PID algorithm, in this algorithm, The fuzzy algorithm is designed to assign (schedule) the correct values of PID K_P, K_I, K_D gains to result in suitable system response. this is accomplished as follows; the fuzzy algorithm, take two signals as inputs; the error signal *e* and rate change of the error *Δe*, these two signal values are used with the knowledge rule base and inference mechanism to calculate the value of the PID three gains K_P, K_I, K_D. These gains are inputted to PID algorithm, which will use it to calculate the control signal.

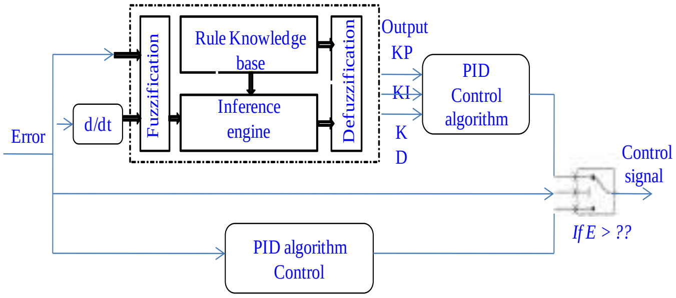

Fig. 3(c)The architecture of applied overall Hybrid artificial fuzzy PID control algorithm

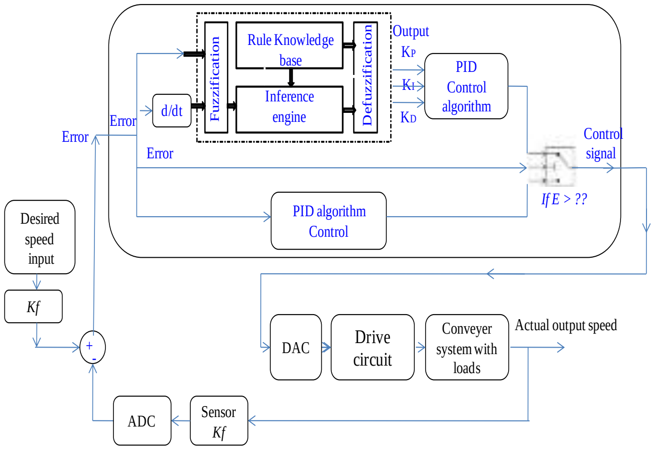

Fig. 3(d) the overall conveyer system with components layout

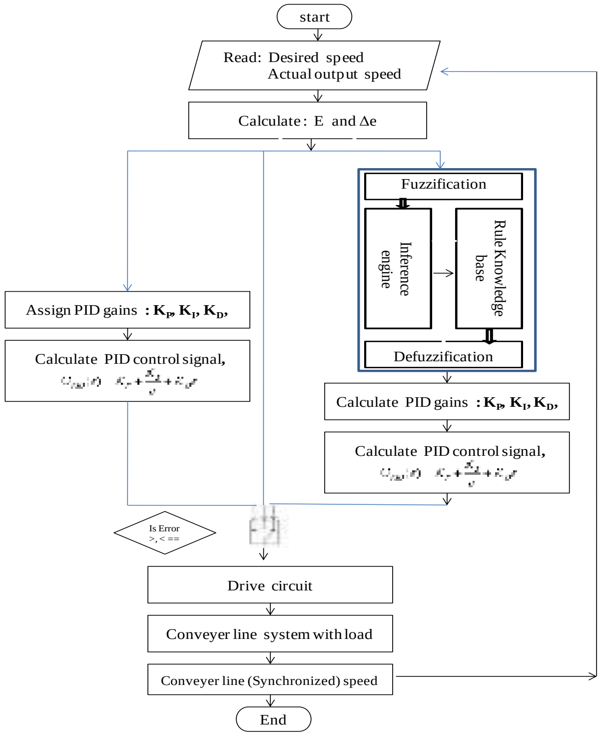

Fig. 3(e).The flowchart representation of the system algorithm design and calculation

3.2.1 PID control algorithm modeling

The PID control algorithm is represented mathematically as given by Eq.(24). To filter the derivative action, a lag filter with coefficient N, is introduced into the algorithm resulting in Eq.(25), the filter with N coefficient is applied to set the filter's pole location.

The microcontroller is used as control unit, it operates on 5VDC. A drive amplifier circuit is required to control the voltage input supply to electric motor that in turn drive the conveyer. The transfer function of the drive/amplifier circuit is given by Eq.(26), where K_a is the maximum and rated input voltage V_{in} to power the electric motor

$$G_{PID}(s) = K_P + \frac{K_I}{s} + K_D s = \frac{\left(K_D s^2 + K_P s + K_I\right)}{s} \tag{24}$$

$$G_{PID}(s) = K_P + \frac{K_I}{s} + K_D\left(\frac{Ns}{s+N}\right) \tag{25}$$

$$G(s) = \frac{K_a}{0.01s+1}, \qquad K_a = 0 - a \quad VDC \tag{26}$$

3.2.2 Selection and modeling of sensing device

The incremental optical encoder is a sensor used to measure the actual output angular position of a motor shaft. In this work, motors speeds synchronization, are done according to shaft position read by the encoder.

Encoder pulses during a sampling interval can be converted to motor speed as given by Eq.(27):

$$C_m = \frac{\pi D_m}{n * N} \tag{27}$$

Assuming the incremental encoder generates as an output N=1000, pulses per one motor' shaft revolution or turn. The proportionality factor K_f equals to the number of units of feedback per one radian of rotation. Encoder with the two channels A and B produces pulses for each encoder rotation. These two pulse signals are shifted by one quarter of a cycle. Since each revolution is 2π radians, the resulting encoder gain in terms of counts/revaluation, is calculated as given by Eq.(28)

The angular speed of the encoder can be calculated by Eq.(28) Where: ω is the encoder angular speed (rad/s), *f* is clock frequency (Hz), *m* is number of clock cycles of the clock signal .Considering an encoder signal frequency of 50 kHz with period of $2*10^{-5}$ s

$$K_f = \frac{4N}{2\pi} \Rightarrow K_f = \frac{4*1000}{2*3.14} = 636.537 \tag{28}$$

$$\omega = \frac{2\pi \mathrm{f}}{Nm} \tag{29}$$

Output RPM = ((Pulses Received in 1 sec * 60) / PPR)

In case the speed is used as sensed variable to close the control loop, Tachometer is a used to read the actual output angular speed, ω_L. Eq.(30) represent the dynamics of the tachometer.

$$V_{out}(t) = K_{tach}\frac{d\theta(t)}{dt} = K_{tach}\omega \Rightarrow K_{tach} = \frac{V_{out}(s)}{\omega(s)} \tag{30}$$

3.2.3 Artificial fuzzy algorithm modeling and design

The architecture of the fuzzy algorithm is shown in Figure 4. The fuzzy algorithm design including the rule base and inference engine that are developed to assign the correct values of PID algorithm parameters, such that the speed can be synchronized

The selected rule inference method is the Mamdani method; meanwhile, for defuzzification the centroid method is applied. To expressing the knowledge levels and represent linguistic variable seven triangular membership functions are used. The Linguistic variables selected are: [NS, NM, NB, Z0, PB, PM, PS]. The developed knowledge rule base and corresponding inference mechanism are shown in rule base Tables 2(a-c).

The ranges for the universes of discourse are normalized in the interval as described in the following; the range for the error *e*,, the rate change of the error *Δe* and proportional gain K_P are normalized in the range is between [-1, 1], meanwhile for the derivative gain K_D the range is between [-0.1, 0.1], finally for the integral gain K_I the range is between [-0.01, 0.01].

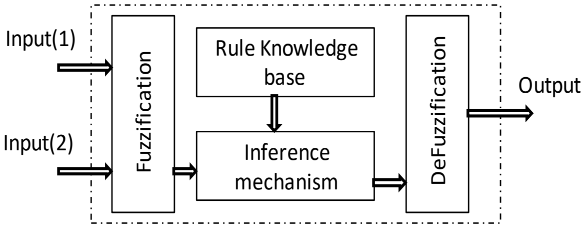

Figure 4 fuzzy algorithm structure

TABLE 2(a) :
the fuzzy rules for scheduling the K_p gain

Δe	*Error*						
	NB	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

TABLE 2(b) :
the fuzzy rules for scheduling the K_D gain

Δe	*Error*						
	NB	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PS	PS	PS	PB

TABLE 2(c) :
the fuzzy rules for scheduling the K_I gain

Δe	*Error*						
	NB	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

4. SYSTEM SIMULATION, TESTING AND DISCUSSION

MATLAB simulink was used to test and evaluate the suggested hybrid algorithm design in achieving a good balance between desired system performance and conveyer system parameter variations.

The algorithms, as well as, the simulation overall system model are developed, such that it can be applied using microcontroller as control unit with operating voltage of 5VDC, and PWM voltage control signal in the range between 0 to 5 VDC, saturation block with ±5 limits was used, drive circuit amplifier with gain suitable for the application.

The developed simulink system model representing the conveyer system including electric motor, load, drive and control algorithm is shown in Figure 5(a). The simulink model with two master slave conveyers for applying Master slave control strategy was built by duplicating the model and shown in Figure 5(b). The developed in MATLAB simulink hybrid fuzzy algorithm with two inputs (*e* and *de/dt*) and three outputs (PID K_P, K_I, K_D gains) is shown in Figure 5(c). The PID simulink submodel is shown in Figure 5(d).the selected triangular membership function with universe of discourse ranges; linguistic variables for the two inputs are shown in Figure 5(e)

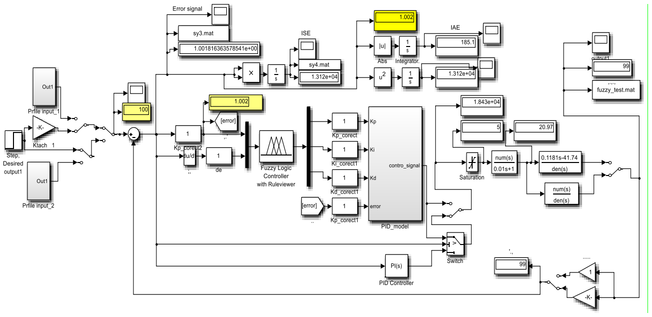

Fig.5(a) The developed overall system simulink model for speed control and synchronization

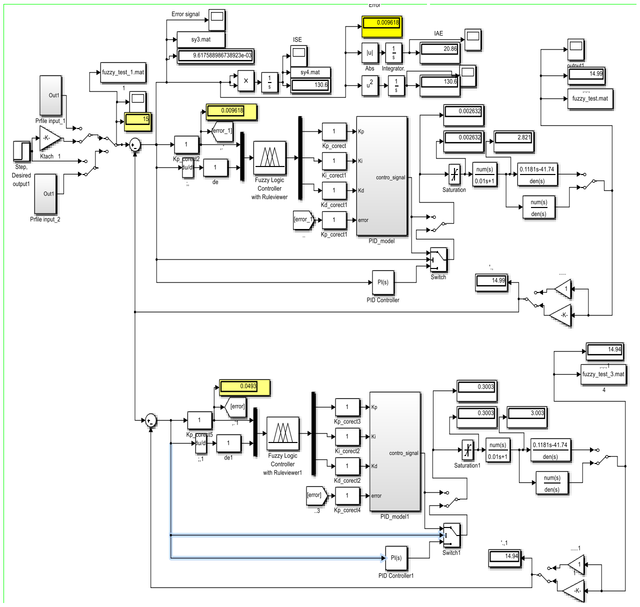

Fig. 5(b) the simulink model with two master and slave conveyers for applying Master slave control strategy

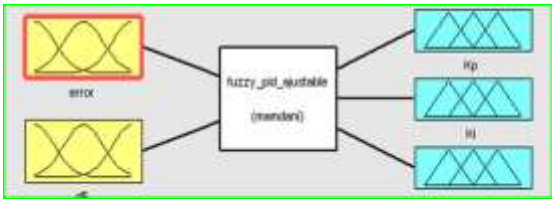

Fig.5(c). The developed in MATLAB simulink hybrid fuzzy algorithm with two input and three outputs

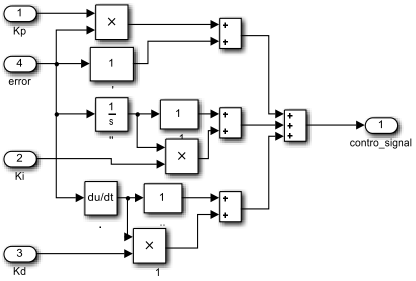

Fig. 5(d) the PID simulink submodel for calculating control signal

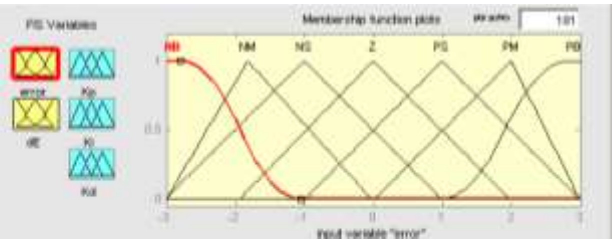

Fig. 5(e) the triangular membership function for the two inputs

4.1 Testing and discussion

TEST (1): Testing the designed both control algorithms (the hybrid fuzzy and PID) for achieving desired output conveyer speed of 100m/s, results in response curve shown in Figure 6(a), the analysis of this curve and referring to listed performance indices shown in table 3, show that the conveyer system achieved desired speed in 4.75 s with 1% overshoot and zero error.

TEST(2): achieving desired conveyer speed of 1 m/s, results in response curve shown in Figure 6 (b), the conveyer system achieved desired speed in 2.31s with zero% overshoot and zero error.

TEST (3): achieving desired conveyer motion profile consisting of speed increase, speed maintaining and speed decrease, results in response curve shown in Figure 6 (c)

TEST(4): testing the overall system consisting of two conveyer lines, master and slave (see Figure 5(b)) to achieve the slave conveyer following the master's speed with motion profile increasing to 30m/s then maintaining this speed and finally reducing to zero with synchronized way ,results in response curve shown in Figure 6 (d). Analyzing the testing result shows that the designed hybrid algorithm is successfully achieved desired system performance resulting in synchronized speed with minimum oscillation overshoot and error

TABLE 3:
Testing result / conveyer system response analysis

№	Desired speed	Actual speed	Error	Rise time	Percent OS%	5T SS time
Test(1)	100	100	0	4.324	1%	4.754
Test(2)	1	1	0	2.31	0	2.31
Test(3)	30	30	0	5	0.5%	8.5

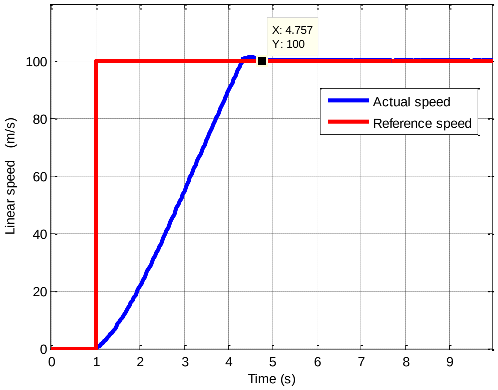

Fig. 6 (a) Test (1): conveyer system response for achieving speed of 100m/s

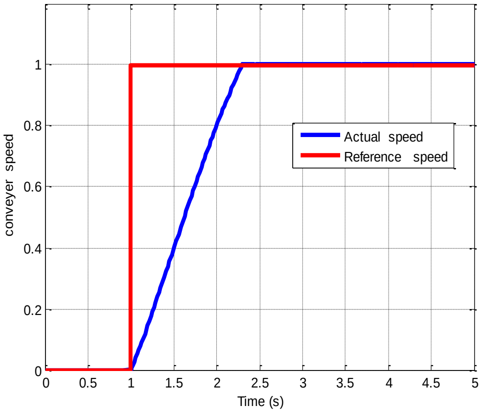

Fig. 6 (b) Test (2): conveyer system response for achieving speed of 1m/s

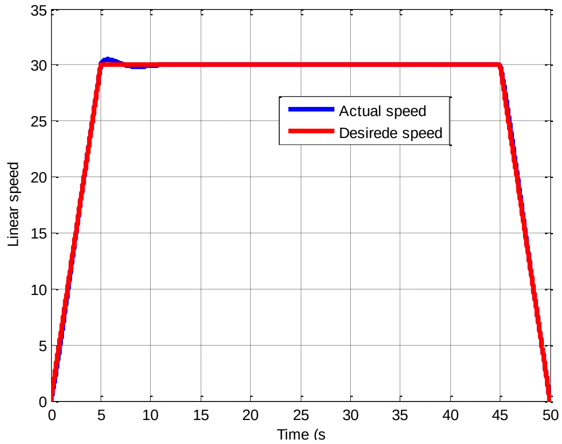

Fig. 6 (c) Test (3): conveyer system response curve achieving desired conveyer motion profile

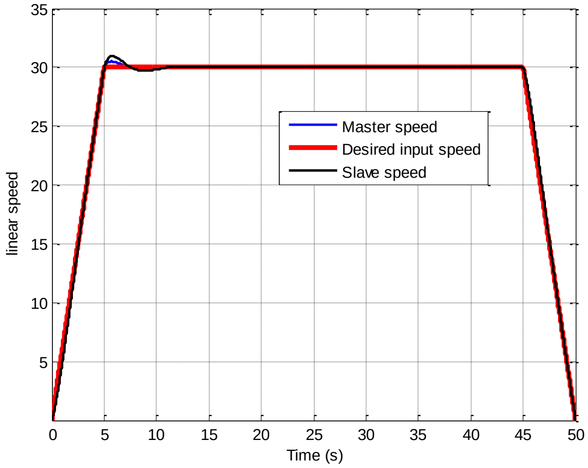

Fig. 6 (d) Test (4): testing the overall system consisting of two conveyer lines, master and slave, for achieving desired motion profile

5. CONCLUSIONS AND FUTURE WORK

Hybrid artificial fuzzy-PID adaptive control algorithm for industrial conveyor lines speed synchroniser was successfully designed and tested. The algorithm is intended for employing in master-slave motion synchronizing control technique and to get a good balance amongst desired system performance and system parameter variations.

Mathematical and simulink models of all the conveyer system components was derived and used to develop the overall system model

Testing the overall system design by subjecting it to different scenarios, including to achieve the required speed of one conveyer with desired performance, also to achieve and synchronize this speed by the other conveyer, show that the algorithm can result in synchronized motion with fast acceptable response speed, short setting time, and minimum both error and overshoot, the algorithm at every point simultaneously throughout the system operation by tracking the accurate reference signal , will properly adjust and allocate the appropriate control voltage signal value to drive the conveyer system to achieve the desired Synchronized speed.

a microcontroller based physical prototype of speed synchronizer is designed and built, the designed and tested hybrid fuzzy PID algorithm is utilized as control algorithm for this prototype. to test the physical prototype in action , two conveyer lines with variable both speed and loads are used, data result will be gathered and analyzed, the synchronizer with the control algorithm will optimized correspondingly.

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