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Research article

Non-linear System Identification and Control for Autonomous Robot Using Artificial Neural Network

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ABSTRACT

The problem of a robot not identifying and accomplishing a particular job assigned to it at a shorter speed and time has reduced the production capacity of some industries that solely depend on robots for their daily production. With this development, the industries do not meet up with their customers' demands thereby making them lose some of their customers. This will equally reduce the financial strength of the industries, as a result of losing some of their customers thereby making them not meet up with paying their staff. If the problem of robot not being able to accomplish a particular job assigned to it at a shorter speed and time is resolved by non-linear system identification and control for an autonomous robot using an artificial neural network, there will be an increase in the production capacity of the industries that have assigned some of their industrial production responsibilities to robots. In this research, a case study of the use of autonomous robots in the production outlay of 7-UP Bottling Company Factory at 9th Mile, Ngwo, was carried out. The need for the use of robots in the factory line production plants was an understudy. It was meant that a robot should be used to replace the work done by men in the packing of produced mineral beverages, otherwise known as soft drinks. Preliminary research showed that robots could be more suitable in that aspect of the production process owing to the enormous strength needed to meet daily production targets. Summary of the research results made relevant revelations. The result obtained when ANN is used is a speed of 13.47m/s while that of using conventional methods like PD or PI is 67.44m/s. With these results, it shows that using ANN accomplished its allotted duty faster at a shorter speed than using a conventional approach like PD or PI

Keywords: *Non-Linear System, Artificial Neural Network, Autonomous Robot, Proportional Integral Derivative*

1. Introduction

Conventional strategies cannot be used in the effective management and control of non-linear systems because of their inability to cope with unknown system dynamics like parameter variation and external disturbances. Non-linear systems cannot be effectively controlled with conventional feedback controllers like the PI, PD, and PID controllers. A new control strategy has to be sought after to solve these problems. ANN controllers are introduced on account of their ability to learn a large class of non-linear functions. ANN can be trained to emulate the unknown, non-linear dynamics by presenting a suitable set of input/output patterns generated by the plant Artificial Neural Network (ANN) operation is based on the operating principle of human neural nature. In this work, an artificial Neural Network (ANN) is used in synthesizing. An autonomous robot is a robot that is designed and engineered to deal with its environment on its own, and work for extended periods without human intervention. Autonomous robots often have sophisticated features that can help them to understand their physical environment Dc motors make robots move, and this movement determines the robot's position. DC motor is widely known as a non-linear system with its non-linear characteristics. These attribute of the dc motor manifests in the robot's inability to attain a precise movement and position.

The problem of a robot not accomplishing jobs assigned to it at a shorter speed and time has reduced the production capacity of some industries that solely depend on robots for their production. With this development, the industries do not meet up with their customers' demands thereby making them lose some of their customers. This will equally reduce the financial strength of the industries, thereby making them not meet up with paying their staff. The problem of the robot not being able to accomplish a job assigned to it at a shorter speed and time can be resolved by non-linear system identification and control for an autonomous robot using an artificial neural network.

In this research, a case study of the use of autonomous robots in the production outlay of 7-UP Bottling Company Factory at 9th Mile, Ngwo, was carried out.

The research aims to achieve non-linear system identification and control for autonomous robot using artificial neural network, and the objectives of the research work are as follows: characterize the study environment and study the identified dynamic properties of a robotic system (speed and position), train the Artificial Neural Network (ANN) in the environment of study, design a model which will use Artificial Neural Network (ANN) to solve the problem, simulate the model in a Simulink environment, obtain a fast response of the system to operational demands and demonstrate through extensive simulation the efficiency of the ANN strategy over the conventional approach like PI, PD, and PID.

Two recently conducted research were used in determining the gap in this research. The first was from Yeong Chin Koo and Elimi Abu Baka on Motor Speed Controller for Differential Wheeled Mobile Robot, 2015. The absence of an intelligent-based controller for fast movement forms the major research gap. Also, from the research presented by Asita Kumar Rath, et al (2018) in Application of Artificial Neural Network for Control and Industrial Navigation of Humanoid Robot, the research gap for this presentation was established. In the presentation, boundary conditions on the training of the ANN put a limitation on the use and application of the humanoid robot in a wide variety of instances including the intended use and control of the robot as expected in this research. This limitation was the research gap which this current research was aimed at closing.

2. Materials and method

The method used was design and implementation

The material used are the mathematical model, parametric data from DC motor, MATLAB, simulations, Basic programming language, Artificial Neural Network, flow chart, designed model of ANN, tables, and graphical presentations.

Methodology

Characterize the study environment and study the identified dynamic properties of a robotic system (speed and position).

Objective one shows how the environment was characterized and also the evaluation of the dynamic properties of a robotic system. This mainly involves the place or environment that the robot will use to do its job or assignment.

The area of the environment by which the robot will operate is taken into consideration. In this case, the length and width of the environment by which the robot will operate are taken into consideration. The robot will pick a processed product at a particular point and relocate it to another point or do any other job assigned to it in that environment.

Length of an office L = width of an office W = 14ft

Change Ft to m

Recall 3Ft = 1M

14Ft = 1 x 14/3 = 4.7m

Area A = L x W

A = 4.7 x 4.7

A = 22.09m^2

The area of the environment is 22.09 meters square

Then studying the identified dynamic properties of a robotic system (speed and position), the figures below shows the dynamic properties

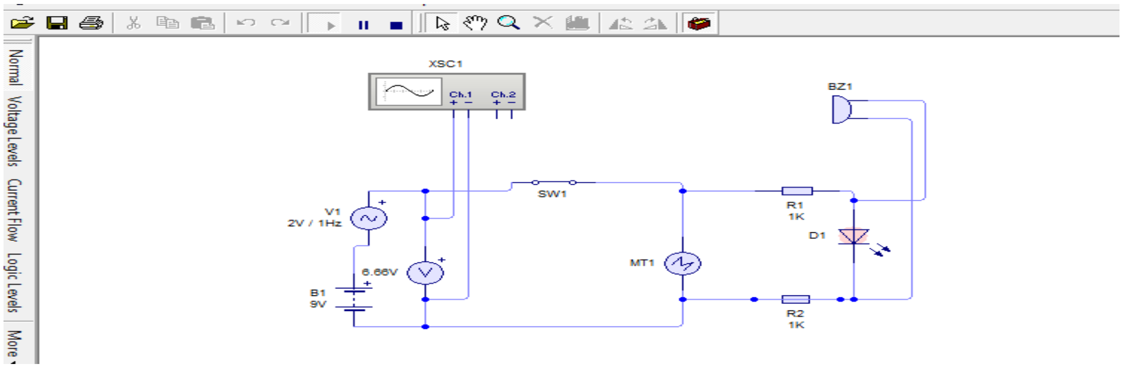


Fig 1: Circuit Diagram Identifying the Dynamic Properties of a Robotic System

Fig 1 shows the working mechanism of the dynamic properties of a robot. The motor accelerates the speed of the robot to meet the determined speed and time. Fig 1 also shows that the geographical position of the motor is at the western point. The properties are speed and position. The circuit monitors the rate of rotation of the motor which also affects the movement of the robot and the value of the voltage (V). At this point, the robot is in motion and yet to complete its targeted speed.

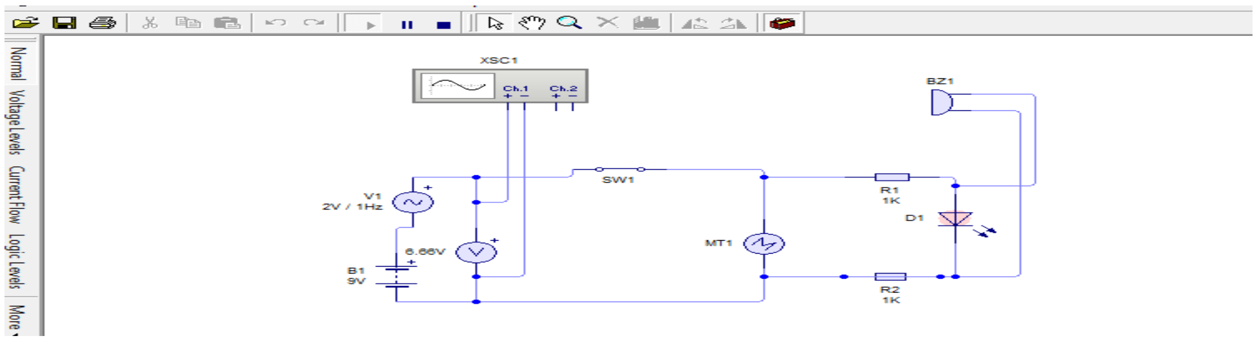


Fig 2: Circuit Diagram Identifying the Dynamic Properties of a Robotic System

Fig .2 shows the circuit diagram of identified dynamic properties of a robotic system in the southern direction. It shows a circuit diagram of identified dynamic properties of a robotic system (speed and position). Fig 2 shows that the motor rotation for the identification of dynamic properties of a robot system is in the southern position. These rotations are observed in figure 2, at this point also it is yet to meet its target.

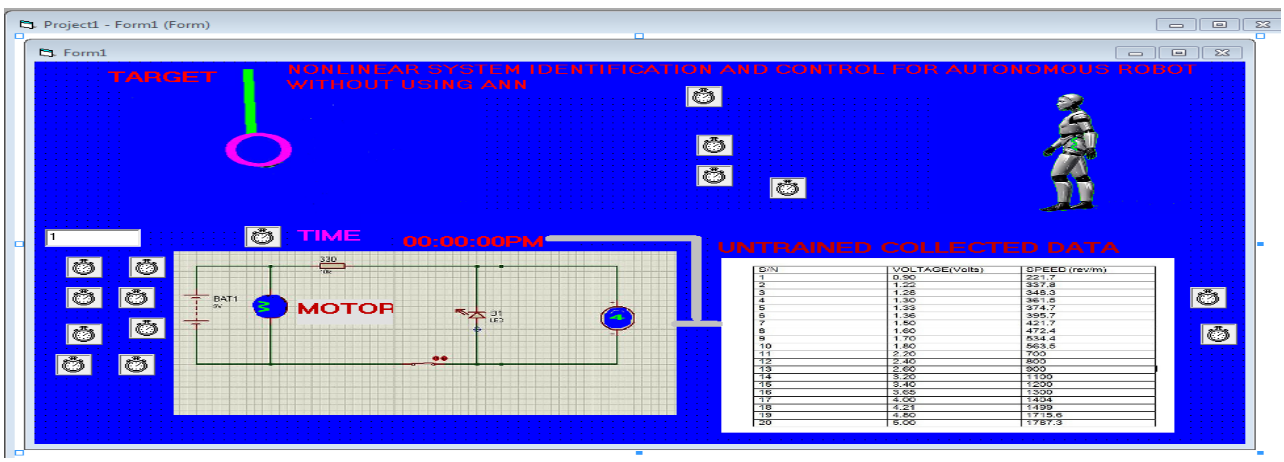


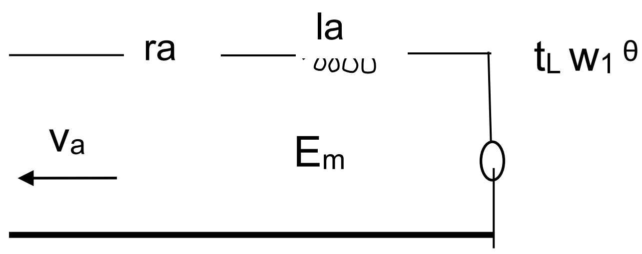
Fig 3: Identified Dynamic Properties of a Robotic System Using Collected Data

Fig 3 shows identified dynamic properties of a robotic system (speed and position) with the data collected from the measurement. Fig 3 shows that the data is not being trained for efficient identification of Non-linear system modeling techniques used in mathematical models to describe the physical phenomena. Non-linear parameter extraction methods essentially extract the values of the parameters used in these models using experimental measurements. Amongst the non-parametric spatial methods, which are mostly in the time domain, pioneering work is done by [Marsi and Caughey 1979]. The movement here is very slow, because of the non-linearity in the dc motor.

Mathematical Model

The mathematical model for the non-linear system identification and control for an autonomous robot using artificial neural network becomes, for us to identify the speed to get the target and the environment of study

The mathematical model can be derived from a schematic diagram of a DC servo motor system shown in figure 1 below. From the diagram, the input is the armature voltage Va in volts being driven by a voltage source. Here the measured variable is the angular velocity of the shaft w measured in rpm and the input voltage in volts.



The following parametric data were collected from the measuring equipment

e_m-Motor back emf = 800N, Ke = motor voltage constant = 59.4V

R – Resistor of the motor = 5 ohms, Ki or K - motor torque constant = 4

$V_a = R_a I_a + L_a \frac{dIa}{dt} + e_m$ ------------------------------ (1)

$e_m = K_e W_m$ ----------------------------------- (2)

$T_m = K_i I_a$ ----------------------------------- (3)

$T_m = I_m W_m + bw_m + T_i$ -------------------------------- (4)

Motor torue, T is related to the armature current I by a constant factor ki

T = K_i --------------------- (6)

The back electromotive force (emf), Vb is related to the angular velocity by

$V_b = K_w = K\frac{d^{\theta}}{dt}$ ------------------- (7)

Applying Norton's laws and kirchoff's laws, the following equations are generated from fig. 1

$J\frac{d2\emptyset}{dt2} + b\frac{d\emptyset}{dt} = K_i$ ----------------------- (8)

$L\frac{di}{dt} + R_i = V - K\frac{d\emptyset}{dt}$ ------------------- (9)

Applying Laplace transform to equation (8) and (9) result in equation (10) and (11) below

$Js^2\emptyset (s) + bs\emptyset (s) = KI (s)$ --------------- (10)

$LsI (s) + RI(s) = V(s) - Ks \emptyset (s)$ -------- (11)

Where s denotes the Laplace operator

From equation (11)

$I_{(s)} = \frac{V(s) - k s \emptyset s}{R + L s}$ ------------------------------ (12)

Then substituting this in equation (10) result in

$Js^2 + bs \emptyset b_s = K\frac{Vs - Ks \emptyset (s)}{R + L s}$ ---------------------------- (13)

Expanding and re- arranging of equation 13 yields the transfer function from input voltage, V(s) to the output angle ∅ in equation 14 below

$$Ga(s) = \frac{\emptyset(s)}{dx} = \frac{1}{s[(R+Ls)(Js+b)+K^2} \text{ ---------------- (14)}$$

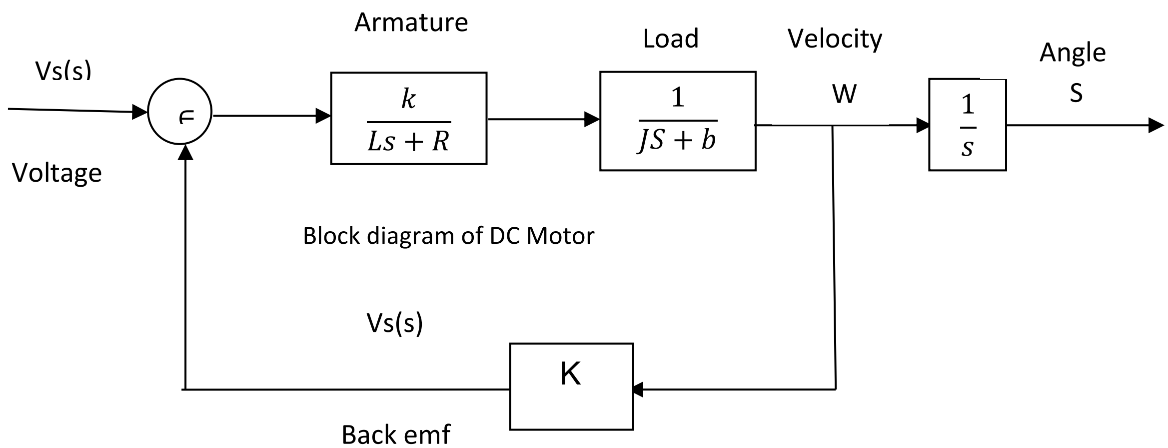
Since Wn = ∅ ------------------------ (15)

Also w(s) = s∅(s) ------------------------- (16)

Substituting ∅ (s) in equation (14) yields the transfer function of input voltage, V(s) to the output angular velocity, w as

$$G(s) = \frac{W(s)}{V(s)} = \frac{k}{(R+Ls)(Js+b)+K^2} \text{ ------------------------------- (17)}$$

These derived equations are shown in the block diagram of figure 2 below



Block diagram of DC Motor

To find an ideal speed the robot will move in the office

$$e_m = K_e W_m \text{ ----------------------------------- (2)}$$

Make W_m the subject formula in equation 2

$W_m = E_m / K_e$

W_m = 800/ 59.4

W_m = 13.468m/s --18

The two things to be considered in this robotic operation are

The area of the environment the robot will operate which is an office of area = 22.09m^2

The speed by which the robot will operate = 13.46m/s

To train the Artificial Neural Network (ANN) in the environment of study.

The area of the environment where the robot will operate coupled with the specified speed the robot will operate will be used to train the artificial neural network. Meanwhile, this training will undergo two stages.

Stage one the area of the environment where the robot will operate which is approximately 22m^2

Area = 22M^2

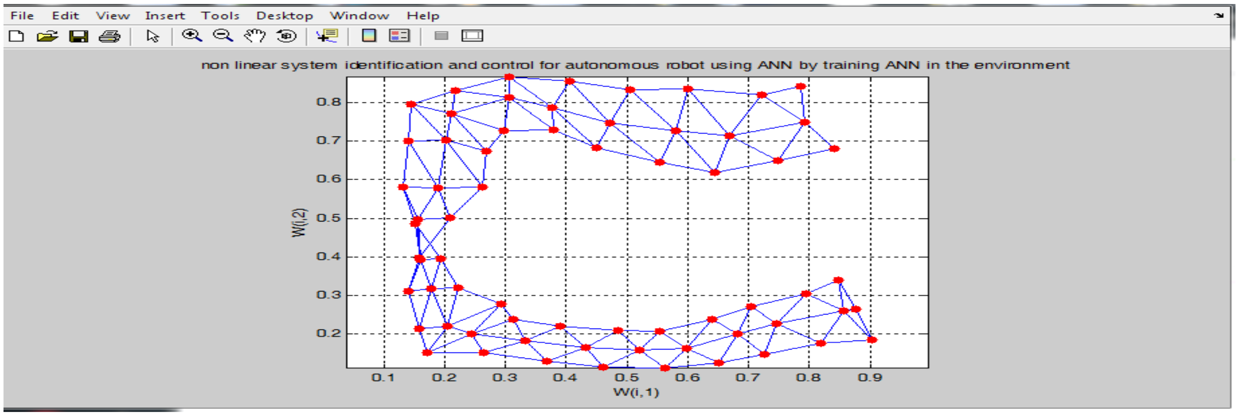


Fig 4: ANN Trained Within the Area of the Environment where the Robot will Operate

Fig 4 shows ANN trained within the area of the environment where the robot will operate. Fig 1 shows that the area of operation of the robot in an office is approximately $22m^2$. Then ANN is trained three times within the area of robot operation. Training becomes = 3 x 22 = 66 neurons.

Stage two the ANN will be trained in the specified speed by which the robot will accomplish its assigned duty within the environment.

Speed by which the robot will operate = 13.47m/s or 14m/s

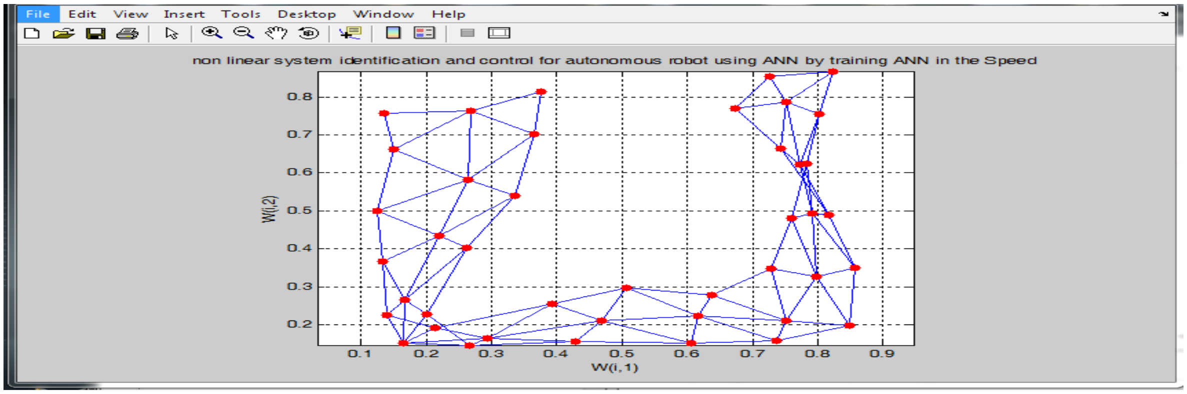


Fig 5: ANN Trained at a Specific Speed the Robot will Operate

Fig 5 shows that the specific speed at which the robot will operate within the office is 14m/s. The number of times ANN will be trained for the robot to operate at a speed of 14m/s is three times which will give forty-two neurons after the training.
Training = 3 x 14 = 42

To design a model which Artificial Neural Network (ANN) will use to solve the problem

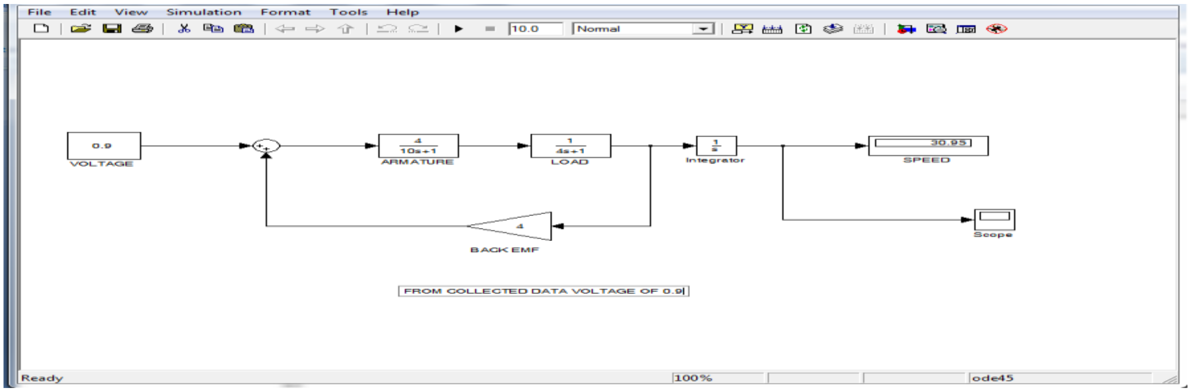
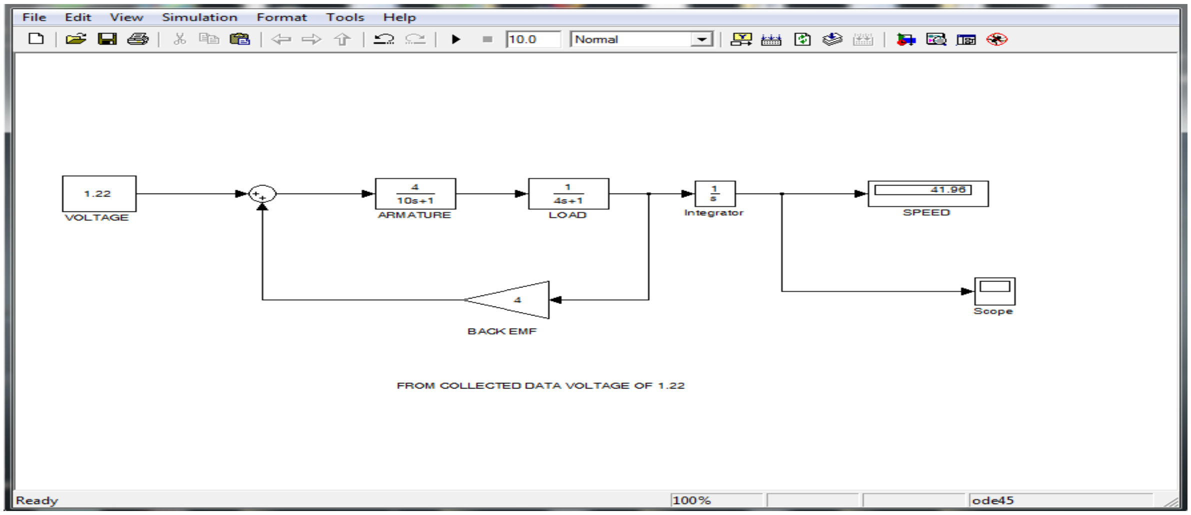


Fig 6: The Designed Model for Robot Operation when the Collected Voltage is 0.9V

Fig 6 shows that the speed of operation of the robot when the collected voltage is 0.9V gives 30.95m/s.



F*ig 7 The Designed Model for Robot Operation when the Collected Voltage is 1.22V*

Fig 7 shows that the speed of operation of the robot when the collected voltage is 1.22V gives 41.95m/s.

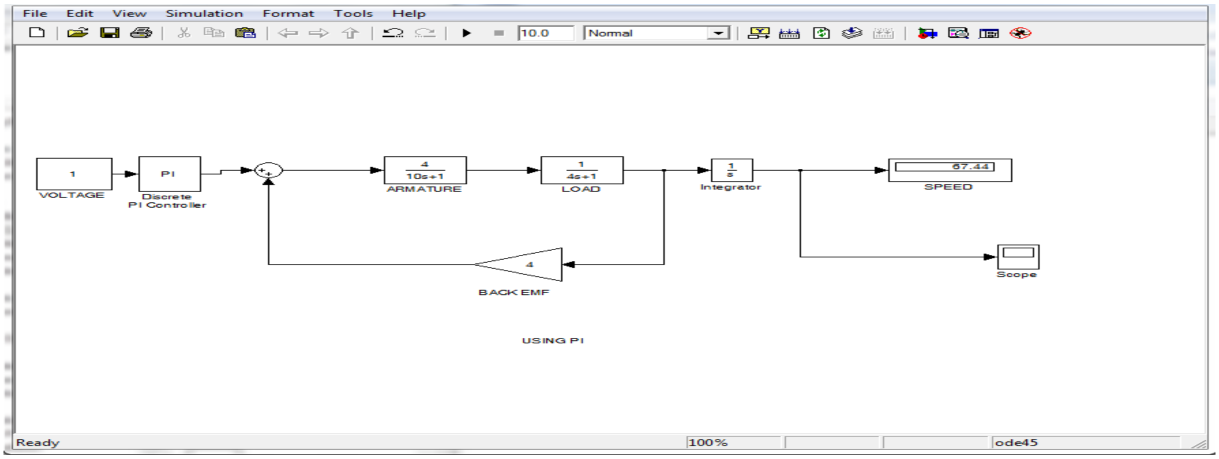


Fig 8: The Designed Model for Robot Operation using Proportional-Integral (PI)

Fig 8 shows the designed model for robot operation using PI. Fig 8 shows that the speed of operation of the robot using proportional-integral is 67.44m/s.

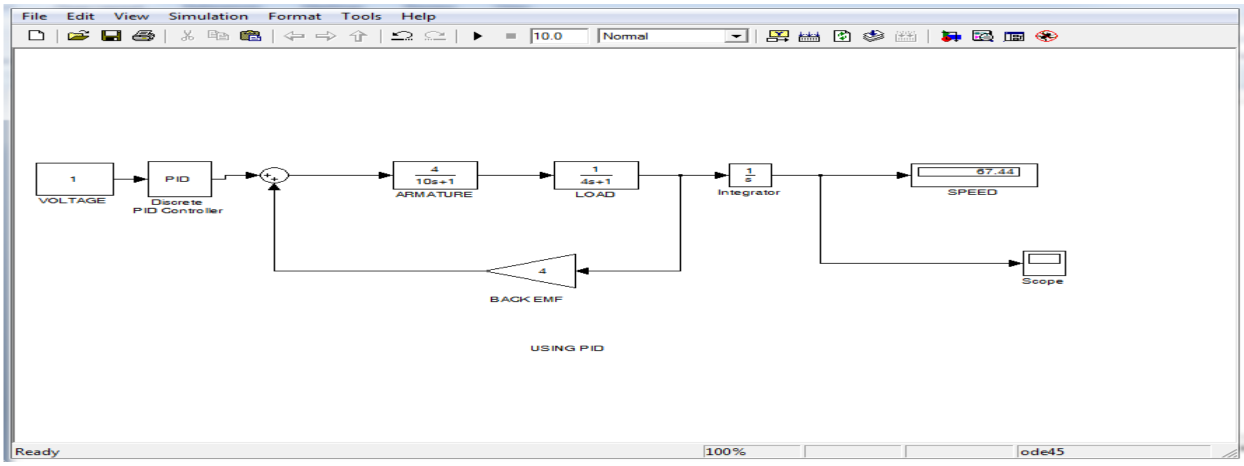


Fig 9: The designed model for robot operation using proportional integral derivative (PID)

Fig 9 shows that the speed of operation of the robot using proportional integral derivative is 67.44m/s.

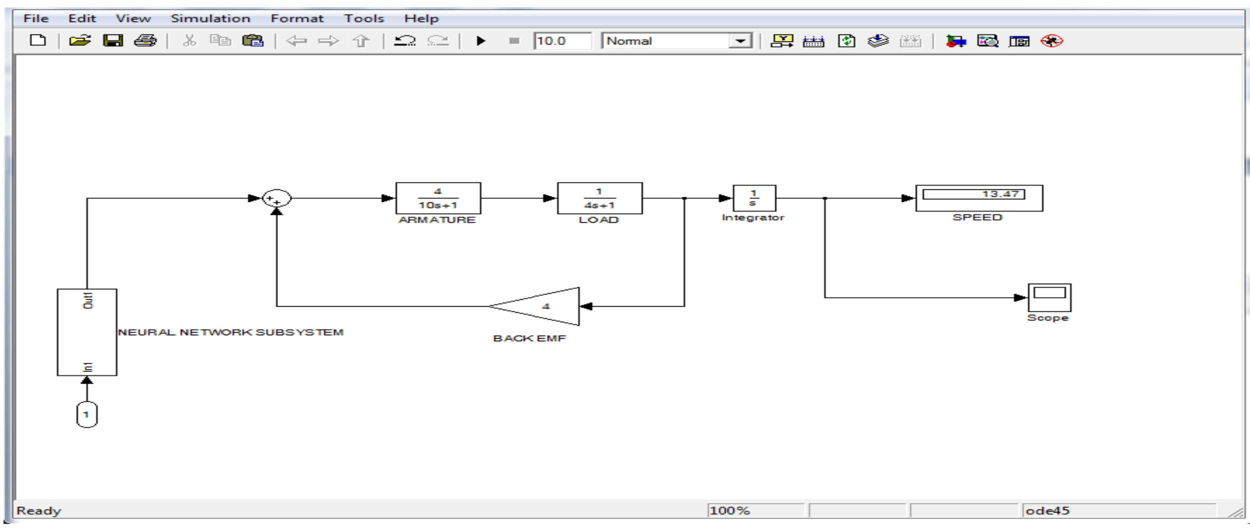


Fig 10: The Designed Model which will Use Artificial Neural Network (ANN) to Solve the Problem

Fig 10 show that the robot speed when trained ANN is incorporated in the model obtains a robotic speed of 13.47m/s.

These results obtained in figures 6, 7, 9, and 10 show that using ANN is best among the collected data and the conventional methods like using PI and PID respectively.

3. Result Analysis

Table 3.1: Speed the Robot Identified the Target Using Conventional PID Vs Time of Identification of the Target By Robot

Speed the Robot Identified the Target Using Conventional pid (m/s)	**Time of Identification of the Target by Robot (s)**
1388. 5195	9.75
1388. 521	9.8
1388.522	9.85
1388.5225	9.9
1388.523	9.95
1390.5225	10

Table 3.1 shows the simulated result of the speed by which a robot identified a target with its corresponding time.

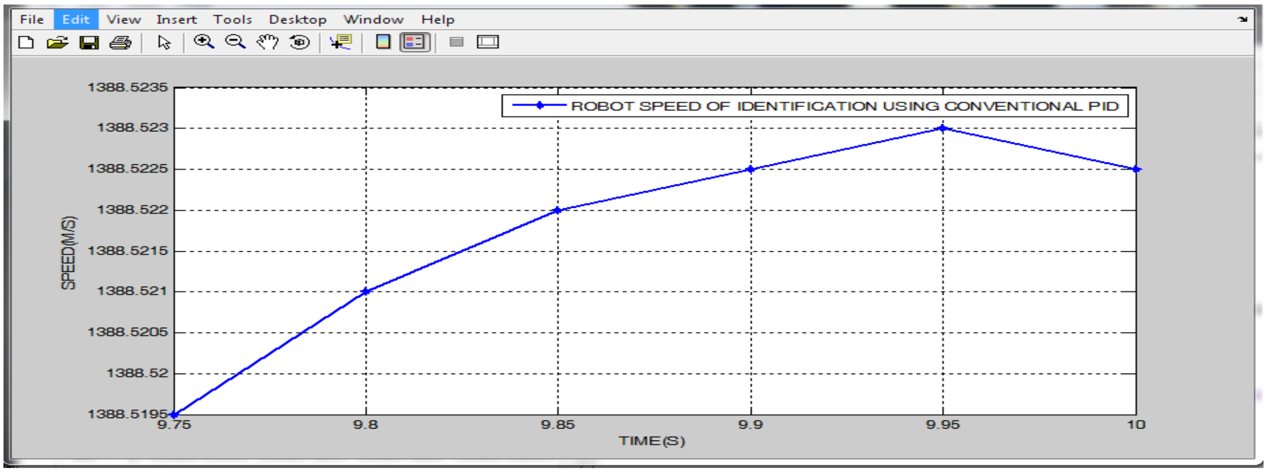


Fig 11: Speed the Robot Identified the Target using Conventional PID vs Time of Identification of the Target by Robot

The highest speed vs time coordination of the robot identification of a target is (1388.523, 9.95). This shows that the robot identified a target at a higher speed of 1388.523m/s.

Table 3.2 Speed the Robot Identified the Target Vs Time the Robot Identified the Target Using ANN

Speed the robot identified the target using ANN	**Time the robot identified the target using ANN**
397.5195	9.75
397.521	9.8
397.522	9.85
397.5225	9.9
397.523	9.95
397.5225	10

Table 3.2 shows the simulated result obtained when the robot identified a target at a specified speed and time

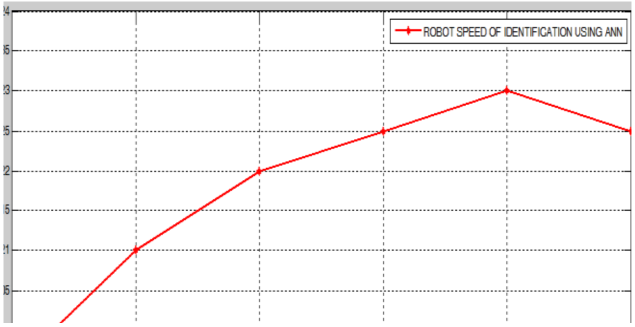


Fig 12: Speed the Robot Identified a Target Vs Time of Identification Using ANN

Fig 12 shows the speed at which the robot identified a target vs time of identification using ANN. Fig 12 shows that the highest speed of identification of a target by a robot verse Time using ANN is (397.523, 9.95). This result shows that the speed of identification of a target by the robot is shorter.

Table 3.3 Comparing the speed robot identified a target (conventionally) using PID and using ANN

Speed the Robot Identified the Target Using ANN	Speed the Robot Identified the Target Using Conventional PID	Speed the Robot Identified the Target Using ANN
397.5195	1388. 5195	9.75
397.521	1388. 521	9.8
397.522	397.522	9.85
397.5225	1388.5225	9.9
397.523	1388.523	9.95
397.5225	1390.5225	10

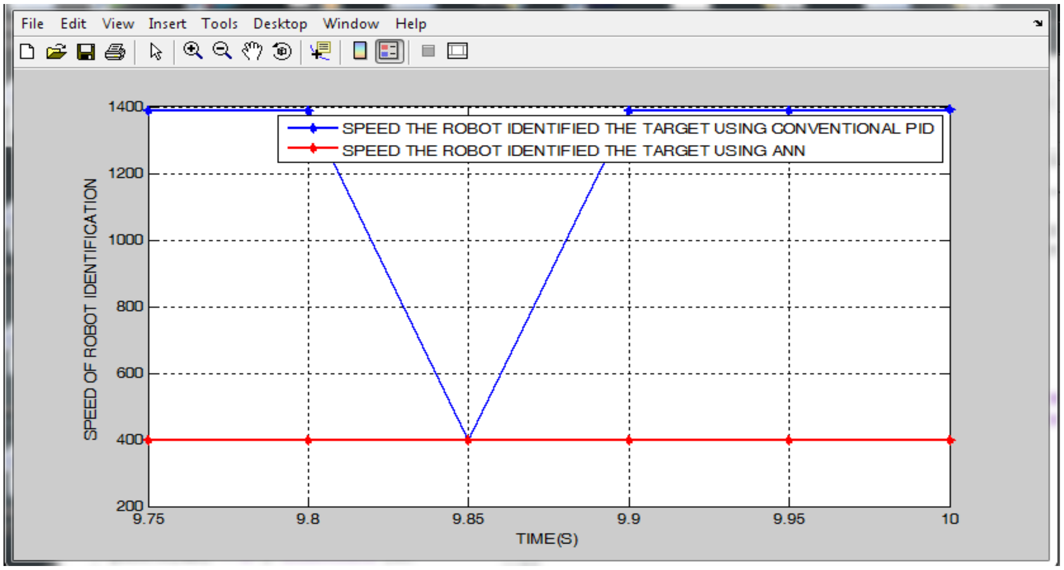


Fig 13: Comparing the Speed Robot Identified a Target (Conventionally) Using PID and Using ANN

The highest speed of identification of a target by a robot at speed vs time of identification using proportional integral derivative (PID) is (1388.523, 9.95) while that of using ANN is (397.523, 9.95). With these results obtained it shows that the speed by which the robot identified a target is shorter than using PID at the same time of 9.95 seconds.

Comparing Speed of the Robot with Collected Data, Artificial Neural Network (ANN) and Conventional PID

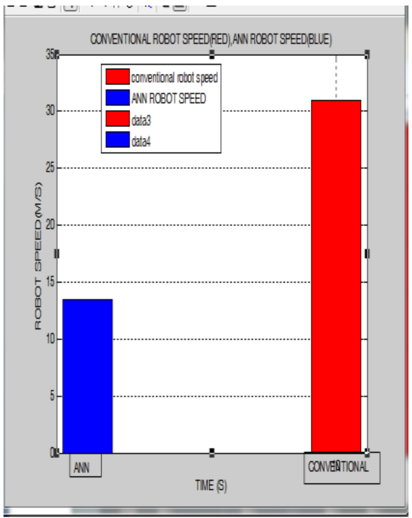


Figure 14

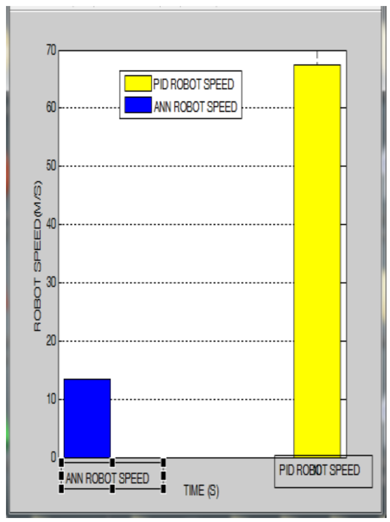


Figure 15

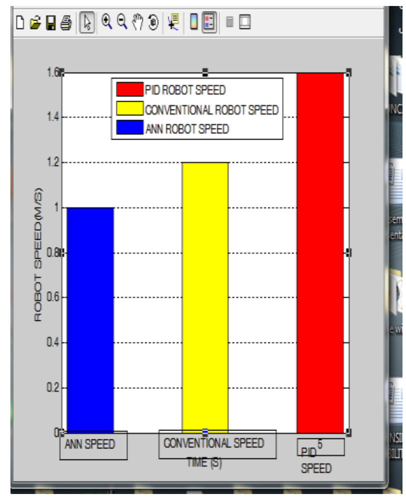


Figure 16

The figures above show that the highest speed of the robot when collected data is used is 30.95m/s, when Artificial Neural Network (ANN) is used is 13.47m/s and when proportional-integral is used is 67.44m/s. The result shows that ANN is better than others with the shortest speed of 13.47m/s

Conclusion

The low speed by which the robot accomplished the duty assigned to it has led to the decrease in the production capacity of the manufacturing companies that solely depend on the robot in their production scheme. To overcome this, the following was done; characterization of the study environment, training of the Artificial Neural Network in the environment of study, design of a model to use Artificial Neural Network to solve the problem, simulations to obtain a fast response of the system in a Simulink environment and demonstrate the efficiency of the ANN strategy over other conventional approaches like PI, PD, and PID.

Recommendations

For an effective identification of a target by a robot, it is recommended that an Artificial Neural Network (ANN) should be incorporated in the system.

Contribution to Knowledge

1. The mathematical model for non-linear system identification and control for an autonomous robot using an artificial neural network was designed

2. The speed of the motor that will control the speed of the robot to accomplish its assignment was analytically obtained from the empirical data collected and ANN was trained in the obtained speed with an artificial intelligent toolbox in MATLAB environment to maintain a shorter speed in accomplishing its allotted duty.

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