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RESEARCH ARTICLE

Identification of Non-Linearities in an Autonomous Robot

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ABSTRACT

Many important industrial processes or systems which can be used to solve day-to-day problems exhibit highly nonlinear behaviors. Such systems are high distillation consumptions systems, highly exothermic chemical reactions, ph. neutralization, batch systems, robotic systems, complicated networks, etc. These processes normally operate over a wide range of conditions due to large process upsets. The effects of non-linearity in any system can cause instability. This paper focused on identifying non-linearity in an autonomous robot. An autonomous robot (robot arm) was the non-linear system that was used to identify the nonlinear effect. From the simulated result presented, the non-linear parameters which were identified and characterized to show the effects of non-linearity are the dead zone and saturation. This paper also succeeded in using non-linear parameter extraction to identify the non-linearity in the robotic arm system.

Keywords: *Non-linearity, Robotic Arm, DC Motor, Dead Zone, Saturation*

1. Introduction

Most often it has been proved by system analysts that real-world dynamic systems exhibit non-linear behavior. According to Khushdep Goyal and Deepark Bhandam 2011, Automation can be defined as the process of following a pre-determined sequence of operations with little or no human intervention, which can require the use of a specific instrument and device that can perform and guide the manufacturing process. (Khushdep Goyal and Deepark Bhandam, 2011) One of the reasons why robots are not common or we do not see many of them walking, riding, or flying around in the streets is because the real world and human beings or societies are so complex that it is impossible to pre-program a robot that can handle every possible situation like humans in an environment. Moreover, robots can be very helpful in our daily life activities, for instance in performing dangerous tasks, repetitive tasks, tasks that require high precision, speed, or computational power, or operating in a situation that is harmful to humans.

From research, most robotic movements are based on the turning or rotation of the shaft of the DC electric motor. This shaft when coupled to gears and drive systems results in the movement and positioning of robots and their arms. The direct current (DC) motor derives its principle from a force that acts on a wire in a magnetic field (Mattias Wahade, 2016). DC motor has some established non-linear properties which are dead zone, saturation, etc. A dead zone can be defined as a condition experienced in a system when the output becomes zero when the input crosses a particular limited value. This is also a situation where the system does not respond to the input until it reached a particular level. In DC electric motor a dead zone effect is often observed due to Coulomb friction at low frequencies (Sean Brenna 1999). Robotic arms are electro-mechanical devices that are used to help humans work fast, with accuracy and precision (Kamlesh Sasane 2014).

This paper identifies nonlinearity in an autonomous robot with the following objectives; characterization of a robotic arm, performing an experiment and measurement to show the effects of nonlinearity, identification of nonlinearities in the robotic arm, and simulating the system to show the effects of nonlinearity in the system

Nonlinear System Identification and Characterization

Research findings show the three major stages of non-linear system identification, non-linear detection, non-linear characterization, and non-linear parameter extraction. According to Aditya Chandrashekhar G., 2009, the first stage is non-linear detection. At this stage, the presence of non-linearity is being detected in the system. The detection is normally done through experimental measurements. The second stage is Non-linear characterization, this stage exposes the type, form and at which point did it occur in the system. The last stage is parameter extraction, this stage involves the identification of the non-linear parameters used in the system.

According to Boeing G, a nonlinear system in physical sciences is a system in which the output is not directly proportional to the input. (Boeing, G. 2016). Problems of non-linear systems are mainly related to engineering and science. Robotic arms are electro-mechanical devices with high accuracy and precision that are used to help humans work fast, (Kamlesh Sasane 2014).

To characterize a robotic arm, the feature of an existing four degree of freedom robotic arm was considered in this paper. Lynx motion AL5A four (4) degrees of freedom robotic arm is an existing robotic arm. Looking at the hardware, it has a single plane shoulder, elbow, wrist motion, and a functional gripper. The body of the arm robot is made of aluminum. The specifications are as follows: 47 gripper axis,180 degrees range of motion per axis., 3.75 inches distance from base to elbow axis, 4.25 inches distance from elbow to wrist axis, 6 inches height (arm parked), 14 inches height (reaching up), and 1.25 inches gripper opening. According to Kaan Yilmaz, the design of a robotic arm depends on the degree of freedom, the joint, and the link (Kaan Yilmaz, Ekrem B, (2017). It was also noticed that a fast robot is more efficient in the system.

2. Materials and Methods

The material used in the research work is as follows: - Parametric data, MATLAB Simulink R2007b version is used in the simulation. Real-Time Windows (RTW) toolbox and Real-time Kernel (OS) inbuilt in MATLAB are used in realizing the Real-Time deployment of the controller, tables, graphical presentations, and laptop computer.

Experiment and measurement were performed and this was used to locate the nonlinear effect in the system. Identification of nonlinearity has been done in this research by carrying out some measurements on DC series servomotor equipment. The effect of saturation and dead zone was seen in the measurement that was carried out. For this research paper, the non-linear control parameters which were identified to show the effects of non-linearity are the dead zone and saturation.

3. Discussions and Analysis

Research shows that robotic movements are based on the turning or rotation of the shaft of the DC electric motor. This shaft when coupled to gears drives the movement and positioning of robots and their arms. Electrical direct current (DC) motors are based on the principle of force that acts on a wire in a magnetic field (Mattias Wahade, 2016). DC motor has some established non-linear properties which are dead zone, saturation, disturbances, backlash, friction, hysteresis, etc. A dead zone is a type of non-linearity shown in various electrical devices like motors, dc servo motors, actuators and can often be observed due to Coulomb friction at low frequencies (Sean Brenna 1999). The non-linear control parameters which were identified and simulated to show the effects of non-linearity are the dead zone and saturation.

Saturation

Experiment and measurement were performed to locate the nonlinear effect in the system and this was shown in parametric data of table 1.0. The effect of saturation was seen in the measurement. This was done using series DC motor equipment (apparatus) set at the specified voltages of table 1.0

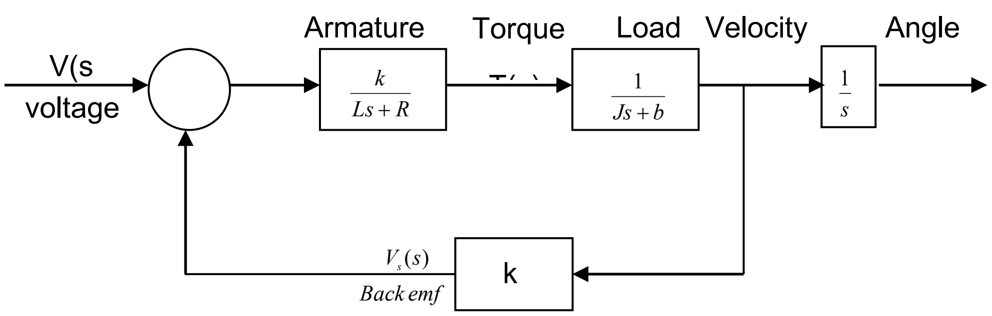

Figure 1: Block diagram of DC motor representing the speed of the robot arm

The block diagram of DC motor machine with model number 63-111-230/5/9. as implemented in Simulink is shown in figure 1.0. In the implementation the actual motor physical parameters are used. Moment of inertia of motor J= 0.0062kg-m^3, damping coefficient b = 0.001Nms/rad, torque constant K_t = 0.06Nm/A, electric resistance (R) = 2.2Ω, electric inductance L = 0.5H, and electromotive force constant K_e = 0.06Vs/rad. Measured result are shown in table 1.0.

Table 3.1: Parametric Data from Series DC Motor Equipment

S/N	Voltage (Volts)	Measured SPEED (rev/m)
1	0.90	212.7
2	1.22	297.8
3	1.28	298.4
4	1.30	306.5
5	1.33	314.7
6	1.36	322.7
7	1.50	351.7
8	1.60	374.4
9	1.70	401.4
10	1.80	420.5
11	2.20	508.9
12	2.40	553.4
13	2.60	603.3
14	3.20	738.5
15	3.40	783.3
16	3.65	839.5
17	4.00	918.4
18	4.21	965.4
19	4.80	1098
20	5.00	1143.5
21	5.80	1322
22	6.20	1412
23	6.80	1547
24	7.00	1547
25	7.50	1547
26	8.20	1547
27	8.80	1547
28	9.50	1547
29	10.00	1547
30	10.5	1547

Non-linearity in a robotic system can be detected from the data collected from the Dc motor. From the data collected it was noticed that at a point, when the voltage increases the speed becomes constant and at this point, the non-linearity was identified and detected. Table1 shows that at the voltage of 6.80V the speed becomes constant and that is the saturation point. It was seen and detected as one of the non-linearity that affects the robot arm. At this point, as the voltage increases the speed remains constant instead of increasing as well.

Dead Zone

Identification of nonlinearity has also been done in this research by carrying out some other measurements on DC series servomotor equipment. The effect of the dead zone was seen in this measurement. From the Servomotor model with sine wave input shown below in figure 2.0, the effect of the dead zone was shown from the data generated from the servomotor model. From the Servomotor model with sine wave input, the effect of the dead zone was shown. Also, the data generated from the servomotor model and the sine wave graph further shows the effects of non-linearity.

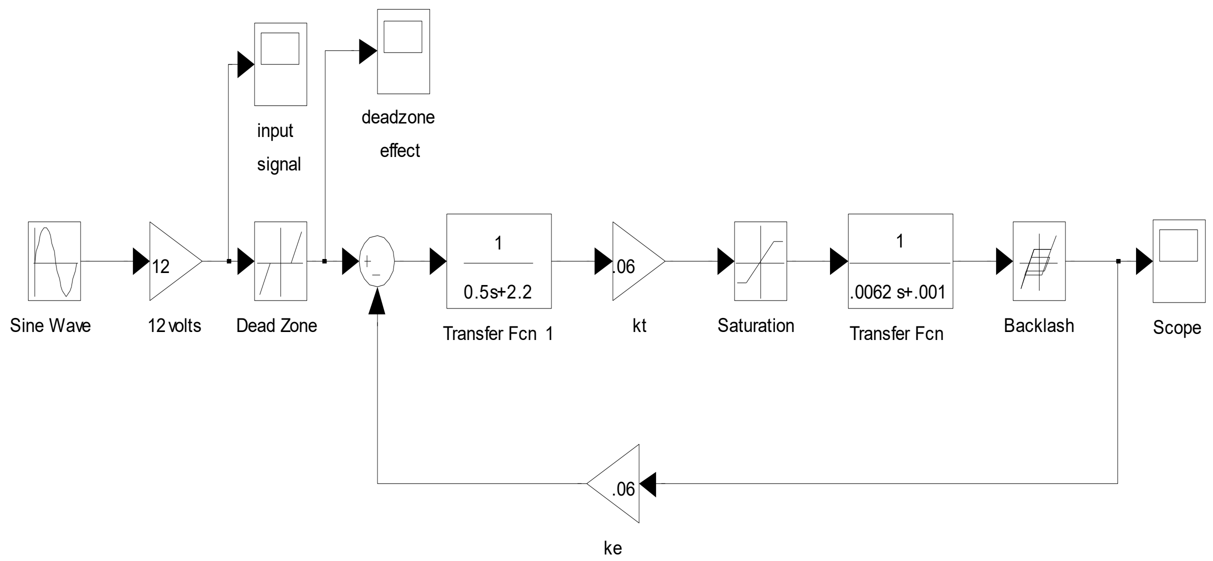

Figure 2: Servomotor model with sine wave input

With the scopes placed at the input before and after the dead zone, and at the output, the effects of the non-linear parameters on the signal can easily be shown on simulating the servomotor model. Simulating the model with a predefined sine wave of 9 volts amplitude and frequency of 6rad/s for 10 seconds generates enough data points for the non-linear effects to be seen and equally enough data to fully represent the system. Table 2.0 below shows the data for the input and the non-linear effects on the servo system.

Table 3.2: Input Data to Servomotor Model before Dead Zone

Time(s)	0.2	0.4	0.6	0.8	1.0	1.2
Voltage	0.0	2.0	3.9	5.6	7.2	8.4
Time(s)	1.40	1.60	1.80	2.0	2.2	2.4
Voltage	9.3	9.9	10.0	9.7	9.1	8.1
Time(s)	2.6	2.8	3.0	3.2	3.4	3.6
Voltage	6.8	5.2	3.3	1.4	-0.6	-2.6
Time(s)	3.8	4.0	4.2	4.4	4.6	4.8
Voltage	-4.4	-6.1	-7.6	-8.7	-9.5	-9.9
Time(s)	5.0	5.2	5.4	5.6	5.8	6.0
Voltage	-10.0	-9.6	-8.8	-7.7	-6.3	-4.6
Time(s)	6.2	6.4	6.6	6.8	7.0	7.2
Voltage	-2.8	-0.6	1.2	3.1	4.9	6.6
Time(s)	7.4	7.6	7.8	8.0	8.2	8.4
Voltage	7.9	9.0	9.7	10.0	9.9	9.4
Time(s)	8.6	8.8	9.0	9.2	9.4	9.6
Voltage	8.5	7.3	5.8	4.1	2.2	0.2
Time(s)	9.8	10.0				

Voltage	-1.7	-3.7				

Figure 5.0 shows the sine waveform as generated while figure 6.0 which was just after the dead zone, shows the dead zone effect. The data in Table 3.2 shows that the time and voltage generated from the sine wave after the dead zone was not stable.

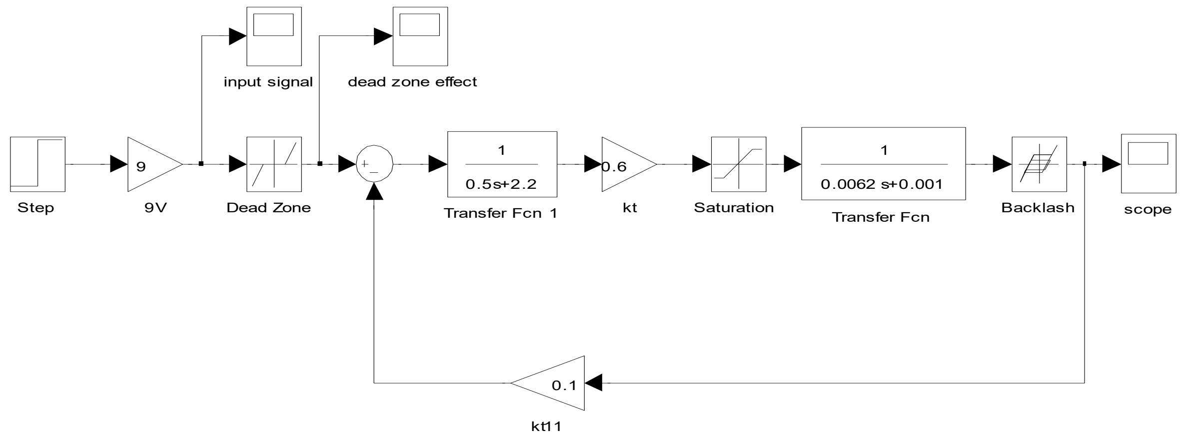

Figure 3: Servomotor Simulink Model with Step Input

Table 3.3 below shows the data input to the servomotor model.

Table 3.3: Step Input data to servomotor model before dead zone

Time(s)	0.2	0.4	0.6	0.8	1.0	1.2
Voltage				2.0	9.0	9.0
Time(s)	1.40	1.60	1.80	2.0	2.2	2.4
Voltage	9.0	9.0	9.0	9.0	9.0	9.0
Time(s)	2.6	2.8	3.0	3.2	3.4	3.6
Voltage	9.0	9.0	9.0	9.0	9.0	9.0
Time(s)	3.8	4.0	4.2	4.4	4.6	4.8
Voltage	9.0	9.0	9.0	9.0	9.0	9.0
Time(s)	5.0	5.2	5.4	5.6	5.8	6.0
Voltage	9.0	9.0	9.0	9.0	9.0	9.0
Time(s)	6.2	6.4	6.6	6.8	7.0	7.2
Voltage	9.0	9.0	9.0	9.0	9.0	9.0
Time(s)	7.4	7.6	7.8	8.0	8.2	8.4
Voltage	9.0	9.0	9.0	9.0	9.0	9.0
Time(s)	8.6	8.8	9.0	9.2	9.4	9.6
Voltage	9.0	9.0	9.0	9.0	9.0	9.0
Time(s)	9.8	10.0				
Voltage	9.0	9.0				

From the data generated and from the plotted input signal after the dead zone shows that more distortions occurred when the signal passes the non-linear parameter, and this reduces the maximum voltage of 9v to 7.8 volts. This can be seen in figures 6.0 and 8.0, which was the graph of the signal generated after dead zone. The results and discussion were shown in that section.

4. Data Presentation and Results

This session shows the data presentation carried out in the research paper and results. Table 3.1 shows the data collected from measurement on series DC motor. The simulation graph of figure 4 shows the non-linear effect on the robotic system.

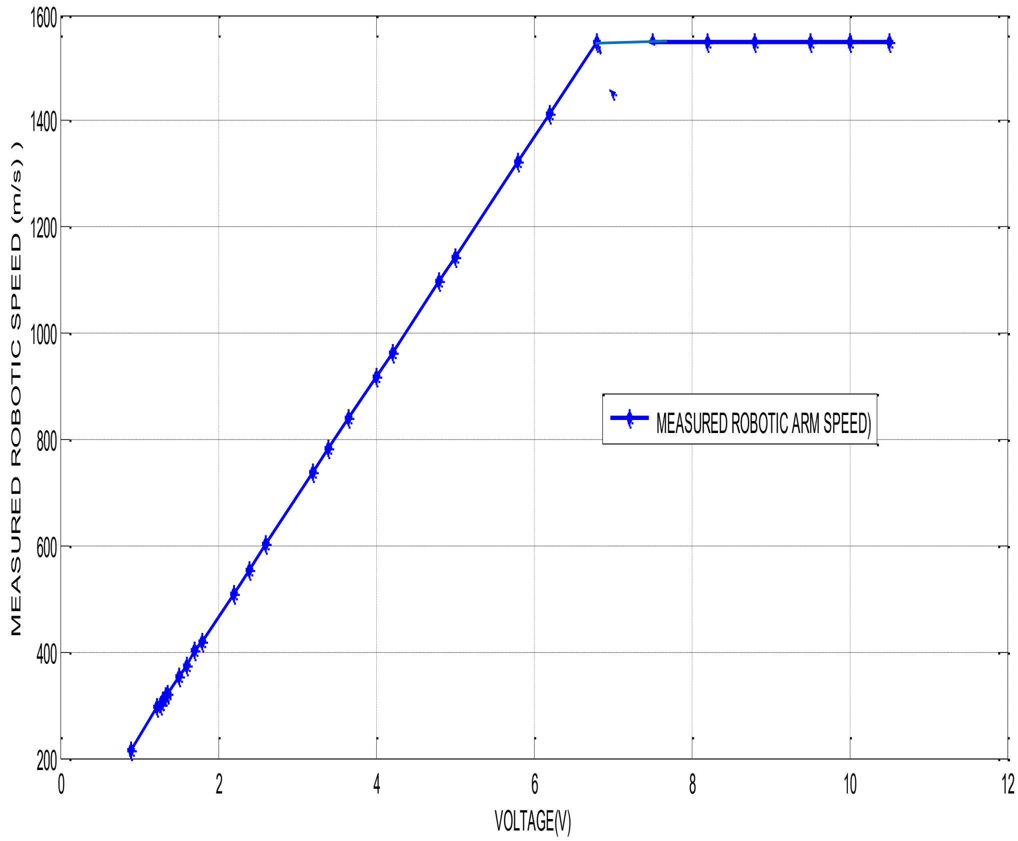

Figure 4: Parametric Data of Speed and Voltage for Motor Operation

Figure 4 shows a graph of parametric data of speed and voltage collected from measurement on Dc series motor equipment. The graph exhibited nonlinearity as shown in figure 4. The graph increases linearly from 212m/s to 1547m/s, it reached its saturation point at 1547m/s at a voltage of 6.80volts.

In the graph, the nonlinearity property of robotic movements was shown. As seen, the graph increases linearly as the voltage increases until further increase in voltage did not result in an additional increase in the speed. Specifically, a linear movement was observed till a certain speed was reached after which the speed stabilizes even with an additional increase in voltage the operating voltage was 6.8V. At that point the voltage of 6.8V, the system experiences saturation point. Also, from that point further increase in voltage results in no increase in speed and the system than experienced dead zone situation. At the point of the dead zone, the system does not respond to the input. The points of saturation and dead zone are the non-linearity that affects the movement and speed of robots.

From the Servomotor model with sine wave input shown in figure 5.0, the effects of the dead zone were shown from the scopes placed at the input before and after the dead zone, and at the output, the effects of the non-linear parameters on the signal can easily be shown on simulating the servomotor model. Simulating the model with a predefined sine wave of 9 volts amplitude and frequency of 6rad/s for 10 seconds generates enough data points for the non-linear effects to be seen and equally enough data to fully represent the system. Table 3.0 shows the data for the input.

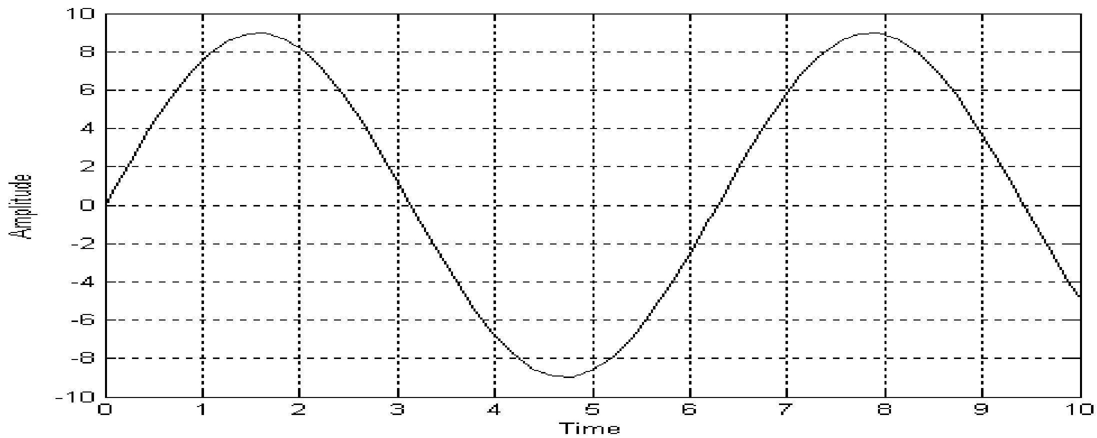

Figure 5: Sine Wave Input

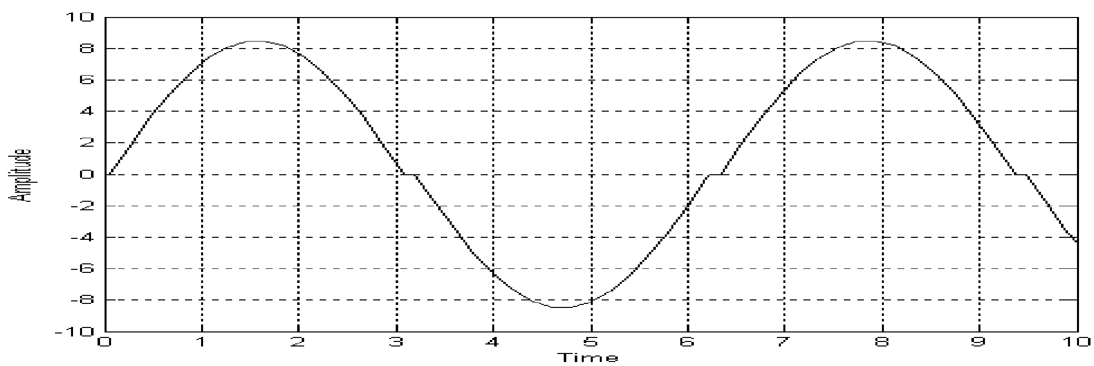

Figure 6: Input Signals After Dead Zone

More distortions are bound to occur by the time the signal passes through the remaining non-linear parameters. To see further effects of non-linear parameters, a single step input signal of the maximum value of 9 volts which is the maximum input of the servomotor in use is applied at the input. This is shown in figure 8 below.

Figures 7 and 8 below show the effect of the dead zone on the signal

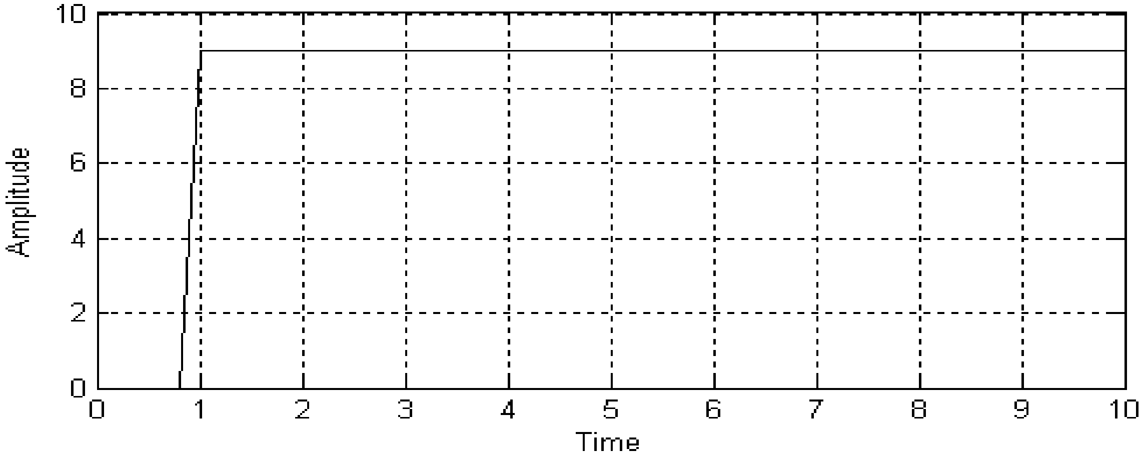

Figure 7: Step input before Dead Zone

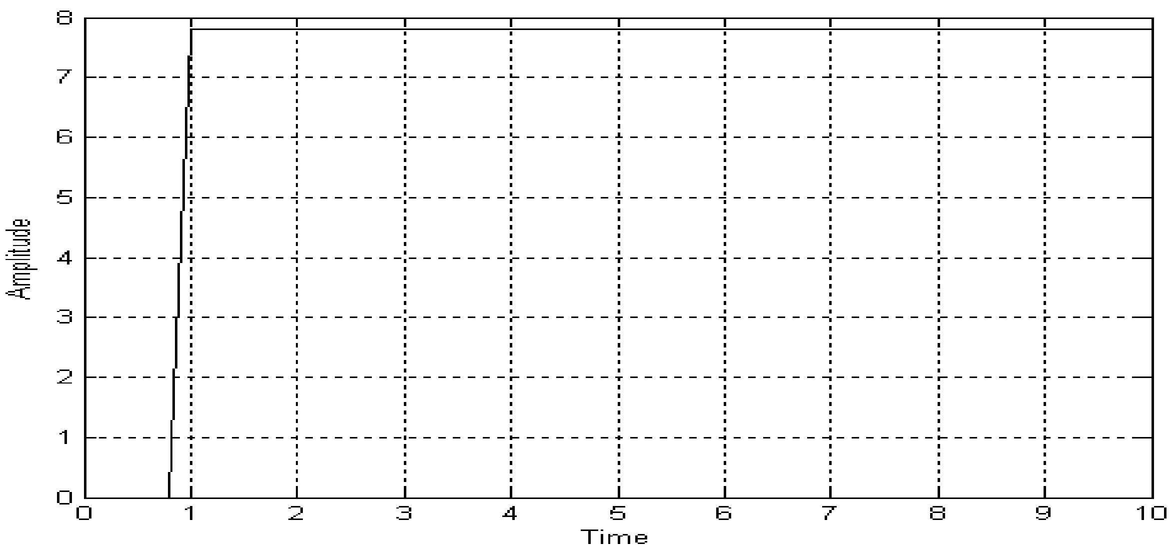

Figure 8: Input signal after the dead zone

To see further effects of non-linearity with a dead zone, a single step input signal of the maximum value of 9 volts which was the input to the servomotor was applied in figure 3.0 The effect of the dead zone was seen in the table 3.0. It was also noticed from the data that the time and voltage generated from the sine wave after the dead zone was not stable and this also shows the effect of non-linearity which was a result of the effect of the dead zone in the system.

5. Conclusion

Identification of nonlinearity in robotic arm movements has been carried out using parameter extraction from the measurements on DC series servomotor equipment. Saturation and dead zone were seen as the non-linearity that affect the system. It was seen that non-linearity in a robotic system can be detected from the data collected from the DC motor which was the means of movement in the robotic system. From the data collected it was noticed that at a point when the voltage increased the speed became constant and at this point the non-linearity was identified and detected. According to Aditya Chandrashekhar G, the nonlinearity effect can be identified using nonlinearity detection, nonlinearity characterization, and non-linearity parameter extraction. This paper has succeeded in using non-linear parameter extraction to identify the non-linearity in a system.

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