NCTF Control Performance Analysis on Rehabilitation Robot

Herianto¹, A F Riyadi ², and H Mastrisiswadi ³
¹, ² Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Indonesia
³ Department of Industrial Engineering, UPN “Veteran” Yogyakarta, Indonesia

E-mail: herianto@ugm.ac.id

Abstract. The need for rehabilitation robots is increasing, while the current price is too high. One reason for the high price of rehabilitation robots is the complicated controller design. For this reason, there is a need for a simpler controller design to be produced at an affordable price. In this study, the NCTF control system tested its performance on a rehabilitation robot prototype with a horizontal linear motion system. The tests are carried out using point to point and set point tracking commands. Point to point testing is carried out at a distance of 50 mm, 150 mm and 230 mm. Meanwhile, set point tracking testing was carried out on the sinusoidal wave with a 100 mm amplitude and a frequency of 0.25 Hz. Both tests were carried out by giving a load of 0 Kg, 0.82 Kg, and 1.64 Kg. The results of this study indicate that the NCTF control provides a good response. The steady-state error value for all point to point motion commands below 2%. As for set point tracking commands, the system can follow orders properly, but there is a 0.24-second delay.

1. Introduction
Stoke is one of the deadliest diseases [1]. Besides death, stroke sufferers often experience paralysis after an attack [1–5]. Therefore, regular physiotherapy is needed, but it requires a long time to be done. This process is conducted by moving paralysed limbs repeatedly [6–9]. Physiotherapy process requires a long time, intensive frequency, and high labour [4,10]. Therefore, robots are now being developed to rehabilitate post-stroke patients to help physiotherapists [10–15]. But to be able to do physiotherapy using a robot costs a lot.

The process of identifying robot rehabilitation needs has been carried out [4,16–18], one of which is low cost and easy to control. During this time, the rehabilitation robot control system is relatively sophisticated, so it requires a high cost to produce it. This control system has a direct impact on increasing the value of rehabilitation robot. To reduce these costs, a simpler and cheaper control system is needed but still reliable. One control system that meets these requirements is the nominal characteristic trajectory following (NCTF). The model on the NCTF control system is not based on complex mathematical calculations but is based on a simple open-loop experiment mechanism. But the control system performance is still unknown. In this research, the performance analysis of the NCTF control system will be carried out on a rehabilitation robot prototype with a horizontal linear motion system.
2. Methods

2.1. Rehabilitation robot prototype with a horizontal linear motion system

The Rehabilitation robot prototype in this study used a belt and pulley mechanism. This prototype has a carriage that can move linearly positively and negatively. Carriage is an eccentric load that can be added with the ballast to increase its weight. The belt connected to the carriage is pulled by a pulley that is rotated by a DC motor. The illustration of this robot prototype can be seen on Figure 1.

![Figure 1. Robot prototype illustration](image)

In addition to the robot prototype, system design is also needed. System design is done by configuring Arduino mega and myRio with a computer and calibrating the encoder. Mega Arduino is connected via MATLAB, while myRio via Labview. MATLAB and LabView are used as user interfaces to program, run, and retrieve data on the controller. Meanwhile, the encoder used to read the displacement of the controller needs to be calibrated to obtain precise results. Calibration is conducted by displaying all data actually when there is a displacement.

2.2. NCTF control system design

The design of the NCTF control system is divided into three stages: (1) moving the system in an open-loop together with calculating displacement and speed, (2) making the NCT system in accordance with the information of the loop-driven system, and (3) designing the PI compensator sought by trial and error method.

![Figure 2 NCT program design using MATLAB](image)

The NCT program design is carried out using MATLAB (Figure 2). In designing NCT, stepwise signals are given to the system in running the control system in an open-loop together with calculating displacement and speed. The step input signal and object response graph can be seen in
Figure 3. The step input signal graph is shown in blue, the object response in the form of displacement is shown in red. Meanwhile, green indicates speed. The results of the NCT design are then the basis for determining the value during trial and error.

**Figure 3** Step input signal and object responses graph

2.3. Experiment

Experiment for the NCTF control system on Rehabilitation robot prototype with a horizontal linear motion system carried out by a point to point and set point tracking commands. Experiment with the command point to point is done by ordering the system to move towards the position of 50 mm, 150 mm and 230 mm. Meanwhile, for experiments with set point tracking commands, the input command is a set point tracking command with a sinusoidal wave with a 100 mm amplitude and a frequency of 0.25 Hz. Both experiments were carried out using loads of 0 Kg, 0.82 Kg and 1.64 Kg. The data collection process in this study can be seen in Figure 4 and the system testing process on Figure 5.

**Figure 4.** Data collection process

**Figure 5.** System testing process

3. Result and Analysis

3.1. NCTF performance evaluation (point to point system)

NCTF performance evaluation is done on point to point and set point tracking systems. The parameter for evaluating the performance of the NCTF control is the overshoot, rise time, settling time, and steady-state values.
At the point to point system testing is carried out at three different distances, that are 50 mm, 150 mm, 230 mm. The response of the system at three different distances is applied for load variations 0 Kg, 0.82 Kg and 1.64 Kg. After the experiment, the response system was obtained with two varieties of loading at each distance. The system response received from the experimental results at a distance of 50 mm can be seen in Figure 6 (a), at a distance of 150 mm in Figure 6 (b), and at a distance of 230 mm in Figure 6 (c). Meanwhile, the parameter data for variations in the two mass loads of each distance can be seen in Table 1.

Based on Figures and Tables, there were no significant differences in parameters for each distance due to differences in load. Parameter differences occur when changes in distance. The overshoot, rise time, and settling time values increase with increasing load. Meanwhile, the largest steady state error value at a distance of 150 mm

| Distance | Mass (Kg) | Overshoot (%) | Rise time (Second) | Settling time (Second) | Steady state error (mm) | Steady state error (%) |
|----------|-----------|---------------|---------------------|------------------------|-------------------------|------------------------|
| 50 mm    | 0         | 17.771        | 0.42                | 0.56                   | 0.809                   | 0.1618                 |
|          | 0.82      | 19.386        | 0.4                 | 0.56                   | 0.809                   | 0.1618                 |
|          | 1.64      | 24.272        | 0.4                 | 1.72                   | 1.2136                  | 0.8091                 |
| 150 mm   | 0         | 96.009        | 0.43                | 2.34                   | 1.2136                  | 0.8091                 |
|          | 0.82      | 86.839        | 0.42                | 2.42                   | 1.0518                  | 0.7012                 |
|          | 1.64      | 91.743        | 0.42                | 2.37                   | 1.2136                  | 0.8090                 |
| 230 mm   | 0         | 363.125       | 0.58                | 3.21                   | 0.5825                  | 0.2533                 |
|          | 0.82      | 374.032       | 0.58                | 3.21                   | 0.7443                  | 0.3236                 |
|          | 1.64      | 374.604       | 0.58                | 3.19                   | 0.3398                  | 0.1477                 |

**Table 1. Parameter data**

**Figure 6.** Point to point system response received at a distance of (a) 50 mm, (b) 150 mm, and (c) 230 mm
3.2. NCTF performance evaluation (Set point tracking system)

In a set point tracking system, the system is given a signal input in the form of a sinusoidal signal with an amplitude of 100 mm, a frequency of 0.25 Hz, and a trial time of 25 seconds. The response of the system is applied to variations in the load of 0 kg can be seen in Figure 7 (a), 0.82 Kg in Figure 7 (b) and 1.64 Kg in Figure 7 (c). Based on the Figure, it can be seen that the system can follow the set point tracking commands properly, but there is a delay of 0.24 seconds for each load. The delay occurs due to the controller limitations, so there is no significant difference in performance with changes in load.

![Graphs showing set point tracking system response](image)

Figure 7. Set point tracking system response in the load of (a) 0 Kg, (b) 0.82 Kg, and (c) 1.64 Kg

4. Conclusion

From this study it was concluded that the movement of linear rehabilitation robots using the NCTF system showed good results. At the point to point command, the steady-state error value is less than 2% for each distance and loading. Meanwhile, on the set point tracking command, the target movement and response are going well. It's just that there is a delay of 0.24 seconds for each load which is a limitation of the controller. Variation of loading only affects the point to point command, while for set point tracking commands no effect.

References

[1] Katan M and Luft A 2018 Global Burden of Stroke *Semin. Neurol.*

[2] Bright F A S, Kayes N M, McPherson K M and Worrall L E 2018 Engaging people experiencing communication disability in stroke rehabilitation: a qualitative study *Int. J. Lang. Commun. Disord.*

[3] Lallukka T, Ervasti J, Lundström E, Mittendorfer-Rutz E, Friberg E, Virtanen M and Alexanderson K 2018 Trends in diagnosis-specific work disability before and after stroke: A longitudinal population-based study in Sweden *J. Am. Heart Assoc.*

[4] Stephenson A and Stephens J 2018 An exploration of physiotherapists’ experiences of robotic
therapy in upper limb rehabilitation within a stroke rehabilitation centre *Disabil. Rehabil. Assist. Technol.*

[5] Benjamin E J, Virani S S, Callaway C W, Chamberlain A M, Chang A R, Cheng S, Chiueh S E, Cushman M, Delling F N, Deo R, De Ferranti S D, Ferguson J F, Fornage M, Gillespie C, Isasi C R, Jiménez M C, Jordan L C, Judd S E, Lackland D, Lichtman J H, Lisabeth L, Liu S, Longenecker C T, Lutsey P L, MacKey J S, Matchar D B, Matsushita K, Mussolino M E, Nasir K, O’Flaherty M, Palaniappan L P, Pandey A, Pandey D K, Reeves M J, Ritchey M D, Rodriguez C J, Roth G A, Rosamond W D, Sampson U K A, Satou G M, Shah S H, Spartano N L, Tirschwell D L, Tsao C W, Voeks J H, Willey J Z, Wilkins J T, Wu J H Y, Alger H M, Wong S S and Muntner P 2018 Heart disease and stroke statistics - 2018 update: A report from the American Heart Association *Circulation*

[6] Wolf S L, Blanton S, Baer H, Breshears J and Butler A J 2002 Repetitive Task Practice: A Critical Review of Constraint-Induced Movement Therapy in Stroke *Neurologist*

[7] Feys H, De Weerdt W, Verbeke G, Steck G C, Capiau C, Kiekens C, Dejaeger E, Van Hoydonck G, Vermeersch G and Cras P 2004 Early and Repetitive Stimulation of the Arm Can Substantially Improve the Long-Term Outcome after Stroke: A 5-Year Follow-up Study of a Randomized Trial *Stroke*

[8] Woldag H, Stupka K and Hummelsheim H 2010 Repetitive training of complex hand and arm movements with shaping is beneficial for motor improvement in patients after stroke *J. Rehhabil. Med.*

[9] Woldag H, Waldmann G, Heuschkel G and Hummelsheim H 2003 Is the repetitive training of complex hand and arm movements beneficial for motor recovery in stroke patients? *Clin. Rehabil.*

[10] Díaz I, Gil J J and Sánchez E 2011 Lower-Limb Robotic Rehabilitation: Literature Review and Challenges *J. Robot.*

[11] Boyard N, Christmann O, Rivette M, Kerbrat O and Richir S 2018 Support optimization for additive manufacturing: Application to FDM *Rapid Prototyp. J.*

[12] Ang K K, Chua K S G, Phua K S, Wang C, Chin Z Y, Kuah C W K, Low W and Guan C 2015 A Randomized Controlled Trial of EEG-Based Motor Imagery Brain-Computer Interface Robotic Rehabilitation for Stroke *Clin. EEG Neurosci.*

[13] Louie D R and Eng J J 2016 Powered robotic exoskeletons in post-stroke rehabilitation of gait: A scoping review *J. Neuroeng. Rehabil.*

[14] Polygerinos P, Wang Z, Galloway K C, Wood R J and Walsh C J 2015 Soft robotic glove for combined assistance and at-home rehabilitation *Robotics and Autonomous Systems*

[15] Kim M S, Kim S H, Noh S E, Bang H J and Lee K M 2019 Robotic-Assisted Shoulder Rehabilitation Therapy Effectively Improved Poststroke Hemiplegic Shoulder Pain: A Randomized Controlled Trial *Arch. Phys. Med. Rehabil.*

[16] Mastrisiswadi H and Herianto H 2015 Identifikasi kebutuhan konsumen robot rehabilitasi pasca stroke dengan menggunakan metode Quality Function Deployment ( QFD ) *SEMINAR NASIONAL TEKNIK INDUSTRI UNIVERSITAS GADJAH MADA 2015* ed B M Sopha and T Wijayanto (Yogyakarta: Universitas Gadjah Mada) pp 27–36

[17] Mastrisiswadi H and Herianto H 2017 Analisis Kebutuhan Robot Rehabilitasi Pasien Pasca Stroke dengan Menggunakan Metode Kano *J. Ilm. Tek. Ind. Vol 15, Iss 2, Pp 151-156 VO - 15*

[18] Mastrisiswadi H and Herianto H 2017 Identifikasi Kepentingan Relatif Konsumen Terhadap Robot Rehabilitasi Pasien Pasca Stroke dengan Menggunakan Conjoint Analysis *J@ti Undip J. Tek. Ind. 12*