

< Back to results | 1 of 11 | Next >

 Download  Print  E-mail  Save to PDF  Save to list | More... >

International Journal of Electrical and Computer Engineering • Open Access • Volume 12, Issue 6, Pages 5967 - 5978 • December 2022

Document type
Article • Gold Open Access • Green Open Access

Source type
Journal

ISSN
20888708

DOI
10.11591/ijece.v12i6.pp5967-5978

Publisher
Institute of Advanced Engineering and Science

Original language
English

View less ^

Control of robot-assisted gait trainer using hybrid proportional integral derivative and iterative learning control

Parikesit, Elang^a  ; Maneetham, Dechrit^a  ; Sutyasadi, Petrus^b 

 Save all to author list

^a Department of Mechatronics Engineering, Rajamangala University of Technology, Thanyaburi, Thailand

^b Mechatronics Department, Faculty of Vocational, Sanata Dharma University, Yogyakarta, Indonesia

23

Views count  

View all metrics >

 View PDF | Full text options ▾ | Export ▾

Abstract

Author keywords

SciVal Topics

Metrics

Abstract

An inexpensive exoskeleton of the lower limb was designed and developed in this study. It can be used as a gait trainer for persons with lower limb problems. It plays an essential role in lower limb rehabilitation and aid for patients, and it can help them improve their physical condition. This paper proposes a hybrid controller for regulating the lower limb exoskeleton of a robot-assisted gait trainer that uses a proportional integral and derivative (PID) controller combined with an iterative learning controller (ILC). The direct current motors at the hip and knee joints are controlled by a microcontroller that uses a preset pattern for the trajectories. It can learn how to monitor a trajectory. If the trajectory or load is changed, it will be able to follow the change. The experiment showed that the PID controller had the smallest overshoot, and settling time, and was responsible for system stability. Even if there are occasional interruptions, the tracking performance improves with the ILC. © 2022 Institute of Advanced Engineering and Science. All rights reserved.

Author keywords

Exoskeleton; Gait trainer; Lower limb; Robotics

SciVal Topics  

Metrics 

Cited by 0 documents

Inform me when this document is cited in Scopus:

Set citation alert >

Related documents

- Limit sets and switching strategies in parameter-optimal iterative learning control
- Owens, D.H. , Tomas-Rodriguez, M. , Daley, S. (2008) *International Journal of Control*
- Reduced-order ILC: The internal model principle reconsidered
- Pipeleers, G. , Moore, K.L. (2011) *Proceedings of the American Control Conference*
- Iterative learning control: Quantifying the effect of output noise
- Owens, D.H. , Liu, S. (2011) *IET Control Theory and Applications*

View all related documents based on references

Find more related documents in Scopus based on:

Authors > | Keywords >

☐ All

☐ CSV export
 ☐ Print
 ☐ E-mail
 ☐ Save to PDF
 Create bibliography

- ☐ 1 Li, Y. R.
 (2015) *Cardiovascular diseases: from molecular pharmacology to evidence-based therapeutics*. Cited 7 times.
 New Jersey: John Wiley & Sons

- ☐ 2 Benjamin, E.J., Blaha, M.J., Chiuve, S.E., Cushman, M., Das, S.R., Deo, R., De Ferranti, S.D., (...), Muntner, P.
 Heart Disease and Stroke Statistics'2017 Update: A Report from the American Heart Association ([Open Access](#))

 (2017) *Circulation*, 135 (10), pp. e146-e603. Cited 6229 times.
<http://circ.ahajournals.org>
 doi: 10.1161/CIR.0000000000000485

[View at Publisher](#)

- ☐ 3 Venketasubramanian, N., Yoon, B.W., Pandian, J., Navarro, J.C.
 Stroke epidemiology in south, east, and south-east asia: A review ([Open Access](#))

 (2017) *Journal of Stroke*, 19 (3), pp. 286-294. Cited 170 times.
<http://j-stroke.org/upload/pdf/jos-2017-00234.pdf>
 doi: 10.5853/jos.2017.00234

[View at Publisher](#)

- ☐ 4 van Nunen, M. P. M.
 (2013) *Recovery of walking ability using a robotic device*. Cited 4 times.
 Amsterdam, Accessed Jul. 06, 2021. [Online]. Available
<https://research.vu.nl/files/42114296/completedissertation.pdf>

- ☐ 5 Do, K. H., Chun, M. H.
 Clinical use of robots as a part of rehabilitation medicine
 (2017) *Brain & Neurorehabilitation*, 10 (1). Cited 2 times.

- ☐ 6 Esquenazi, A.
 Comment on "assessing Effectiveness and Costs in Robot-Mediated Lower Limbs Rehabilitation: A Meta-Analysis and State of the Art" ([Open Access](#))

 (2018) *Journal of Healthcare Engineering*, 2018, art. no. 7634965. Cited 5 times.
<http://www.hindawi.com/journals/jhe/contents/>
 doi: 10.1155/2018/7634965

[View at Publisher](#)

- ☐ 7 Radjou, N., Prabhu, J.
 (2015) *Frugal innovation: How to do better with less*. Cited 169 times.
 London: Profile Books

- ☐ 8 Tran, V.-T., Ravaud, P.
 Frugal innovation in medicine for low resource settings ([Open Access](#))

 (2016) *BMC Medicine*, 14 (1), art. no. 102. Cited 60 times.
<http://www.biomedcentral.com/bmcmed/>
 doi: 10.1186/s12916-016-0651-1

[View at Publisher](#)

-
- ☐ 9 Huang, S.-J., Lee, J.-S.
A stable self-organizing fuzzy controller for robotic motion control
(2000) *IEEE Transactions on Industrial Electronics*, 47 (2), pp. 421-428. Cited 103 times.
doi: 10.1109/41.836358
[View at Publisher](#)
-
- ☐ 10 Yoo, B.K., Ham, W.C.
Adaptive control of robot manipulator using fuzzy compensator
(2000) *IEEE Transactions on Fuzzy Systems*, 8 (2), pp. 186-199. Cited 271 times.
doi: 10.1109/91.842152
[View at Publisher](#)
-
- ☐ 11 Bristow, D.A., Tharayil, M., Alleyne, A.G.
Survey Of Iterative Learning Control: A Learning-Based Method for High-Performance Tracking Control
(2006) *IEEE Control Systems*, 26 (3), pp. 96-114. Cited 2282 times.
doi: 10.1109/MCS.2006.1636313
[View at Publisher](#)
-
- ☐ 12 Bristow, D. A., Barton, K. L., Alleyne, A. G.
(2011) *Iterative learning control, Control Sy*
Ed. Boca Raton: CRC Press
-
- ☐ 13 Madady, A.
PID type iterative learning control with optimal gains
(2008) *International Journal of Control, Automation and Systems*, 6 (2), pp. 194-203. Cited 63 times.
-
- ☐ 14 Majeed, A.P.P.A., Taha, Z., Abidin, A.F.Z., Zakaria, M.A., Khairuddina, I.M., Razman, M.A.M., Mohamed, Z.
The Control of a Lower Limb Exoskeleton for Gait Rehabilitation: A Hybrid Active Force Control Approach ([Open Access](#))
(2017) *Procedia Computer Science*, 105, pp. 183-190. Cited 18 times.
<http://www.sciencedirect.com/science/journal/18770509>
doi: 10.1016/j.procs.2017.01.204
[View at Publisher](#)
-
- ☐ 15 Amiri, M.S., Ramli, R., Ibrahim, M.F.
Initialized Model Reference Adaptive Control for Lower Limb Exoskeleton ([Open Access](#))
(2019) *IEEE Access*, 7, art. no. 8906124, pp. 167210-167220. Cited 24 times.
<http://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=6287639>
doi: 10.1109/ACCESS.2019.2954110
[View at Publisher](#)
-
- ☐ 16 Tucker, M.R., Olivier, J., Pagel, A., Bleuler, H., Bouri, M., Lamercy, O., Del Millán, J.R., (...), Gassert, R.
Control strategies for active lower extremity prosthetics and orthotics: A review ([Open Access](#))
(2015) *Journal of NeuroEngineering and Rehabilitation*, 12 (1), art. no. 1. Cited 487 times.
<http://www.jneuroengrehab.com/home/>
doi: 10.1186/1743-0003-12-1
[View at Publisher](#)
-
- ☐ 17 Maneetham, D.
(2018) *Industrial robotics & mechatronics applications*
Bangkok: SE-Education
-

- 18 Hamill, J., Knutzen, K. M., Derrick, T. R.
(2015) *Biomechanical basis of human movement*. Cited 398 times.
4th ed. Philadelphia: Lippincott Williams & Wilkins
-
- 19 Low, K.H.
Robot-assisted gait rehabilitation: From exoskeletons to gait systems

(2011) *2011 Defense Science Research Conference and Expo, DSR 2011*, art. no. 6026886. Cited 71 times.
ISBN: 978-142449276-3
doi: 10.1109/DSR.2011.6026886

View at Publisher
-
- 20 Moreno, J.C., Brunetti, F., Rocon, E., Pons, J.L.
Immediate effects of a controllable knee ankle foot orthosis for functional compensation of gait in patients with proximal leg weakness

(2008) *Medical and Biological Engineering and Computing*, 46 (1), pp. 43-53. Cited 38 times.
doi: 10.1007/s11517-007-0267-x

View at Publisher
-
- 21 Hollerbach, J. M., Hunter, I. W., Ballantyne, J.
(1992) *A comparative analysis of actuator technologies for robotics*. Cited 271 times.
Cambridge: The MIT Press
-
- 22 Ziegler, J.G., Nichols, N.B.
Optimum settings for automatic controllers

(1993) *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, 115 (2B), pp. 220-222. Cited 433 times.
doi: 10.1115/1.2899060

View at Publisher
-
- 23 Ang, K.H., Chong, G., Li, Y.
PID control system analysis, design, and technology (Open Access)

(2005) *IEEE Transactions on Control Systems Technology*, 13 (4), pp. 559-576. Cited 2025 times.
doi: 10.1109/TCST.2005.847331

View at Publisher
-
- 24 Åström, K.J., Hägglund, T., Hang, C.C., Ho, W.K.
Automatic tuning and adaptation for PID controllers - a survey

(1993) *Control Engineering Practice*, 1 (4), pp. 699-714. Cited 524 times.
doi: 10.1016/0967-0661(93)91394-C

View at Publisher
-
- 25 Somefun, O.A., Akingbade, K., Dahunsi, F.
The dilemma of PID tuning

(2021) *Annual Reviews in Control*, 52, pp. 65-74. Cited 24 times.
<https://www.journals.elsevier.com/annual-reviews-in-control>
doi: 10.1016/j.arcontrol.2021.05.002

View at Publisher
-
- 26 Sutyasadi, P., Parnichkun, M.
Push recovery control of quadruped robot using particle swarm optimization based structure specified mixed sensitivity H_2/H_∞ control

(2020) *Industrial Robot*, 47 (3), pp. 423-434. Cited 4 times.
<http://www.emeraldinsight.com/info/journals/ir/ir.jsp>
doi: 10.1108/IR-06-2019-0135

View at Publisher
-

- 27 Hasan, M.W., Abbas, N.H.
An improved swarm intelligence algorithms-based nonlinear fractional order-PID controller for a trajectory tracking of underwater vehicles (Open Access)
(2020) *Telkomnika (Telecommunication Computing Electronics and Control)*, 18 (6), pp. 3173-3183. Cited 8 times.
<http://journal.uad.ac.id/index.php?journal=TELKOMNIKA&page=issue&op=archive>
doi: 10.12928/TELKOMNIKA.v18i6.16282
View at Publisher
-
- 28 Faraj, M.A., Abbood, A.M.
Fractional order PID controller tuned by bat algorithm for robot trajectory control (Open Access)
(2021) *Indonesian Journal of Electrical Engineering and Computer Science*, 21 (1), pp. 74-83. Cited 7 times.
<http://ijeecs.iaescore.com/index.php/IJECS/article/view/22600/14436>
doi: 10.11591/ijeecs.v21.i1.pp74-83
View at Publisher
-
- 29 Abdulhussein, K.G., Yasin, N.M., Hasan, I.J.
Comparison between butterfly optimization algorithm and particle swarm optimization for tuning cascade pid control system of pm dc motor (Open Access)
(2021) *International Journal of Power Electronics and Drive Systems*, 12 (2), pp. 736-744. Cited 4 times.
<http://ijpeds.iaescore.com/index.php/IJPEDS/article/view/21176>
doi: 10.11591/ijpeds.v12.i2.pp736-744
View at Publisher
-
- 30 Shah, J. A., Rattan, S. S.
Dynamic analysis of two link robot manipulator for control design using PID computed torque control
(2016) *IAES International Journal of Robotics and Automation (IJRA)*, 5 (4), pp. 277-283. Cited 5 times.
Dec
-
- 31 Kane, S.N., Mishra, A., Dutta, A.K.
Preface: International Conference on Recent Trends in Physics (ICRTP 2016) (Open Access)
(2016) *Journal of Physics: Conference Series*, 755 (1), art. no. 011001. Cited 154 times.
<http://www.iop.org/EJ/journal/conf>
doi: 10.1088/1742-6596/755/1/011001
View at Publisher
-
- 32 Erenoglu, I., Eksin, I., Yesil, E., Guzelkaya, M.
An intelligent hybrid fuzzy PID controller
(2006) *20th European Conference on Modelling and Simulation: Modelling Methodologies and Simulation Key Technologies in Academia and Industry, ECMS 2006*, pp. 62-66. Cited 46 times.
ISBN: 0955301807; 978-095530180-3
doi: 10.7148/2006-0062
View at Publisher
-
- 33 Abidi, K., Xu, J.-X.
(2015) *Advanced discrete-time control*, 23. Cited 22 times.
Singapore: Springer Singapore
-
- 34 Somwanshi, D., Bunde, M., Kumar, G., Parashar, G.
Comparison of fuzzy-PID and PID controller for speed control of DC motor using LabVIEW (Open Access)
(2019) *Procedia Computer Science*, 152, pp. 252-260. Cited 36 times.
<http://www.sciencedirect.com/science/journal/18770509>
doi: 10.1016/j.procs.2019.05.019
View at Publisher

- 35 Razak Ramesh, N.H.A., Ghazali, M.R., Ahmad, M.A.
Sigmoid pid based adaptive safe experimentation dynamics algorithm of portable duodopa pump for parkinson's disease patients ([Open Access](#))
(2021) *Bulletin of Electrical Engineering and Informatics*, 10 (2), pp. 632-639. Cited 2 times.
<https://beei.org/index.php/EEI/article/view/2542/2108>
doi: 10.11591/eei.v10i2.2542
[View at Publisher](#)
-
- 36 Sanfelice, R. G.
(2021) *Hybrid feedback control*. Cited 32 times.
Princeton: Princeton University Press
-
- 37 Arimoto, S., Kawamura, S., Miyazaki, F.
Bettering operation of Robots by learning
(1984) *Journal of Robotic Systems*, 1 (2), pp. 123-140. Cited 2896 times.
doi: 10.1002/rob.4620010203
[View at Publisher](#)
-
- 38 Owens, D.H., Hätönen, J.
Iterative learning control - An optimization paradigm
(2005) *Annual Reviews in Control*, 29 (1), pp. 57-70. Cited 185 times.
doi: 10.1016/j.arcontrol.2005.01.003
[View at Publisher](#)
-
- 39 Chen, F.-M., Tsai, J.S.-H., Liao, Y.-T., Guo, S.-M., Ho, M.-C., Shaw, F.-Z., Shieh, L.-S.
An improvement on the transient response of tracking for the sampled-data system based on an improved PD-type iterative learning control
(2014) *Journal of the Franklin Institute*, 351 (2), pp. 1130-1150. Cited 22 times.
doi: 10.1016/j.jfranklin.2013.10.014
[View at Publisher](#)
-
- 40 Li, X., Ren, Q., Xu, J.-X.
Precise Speed Tracking Control of a Robotic Fish Via Iterative Learning Control
(2016) *IEEE Transactions on Industrial Electronics*, 63 (4), art. no. 7327189, pp. 2221-2228. Cited 83 times.
<http://ieeexplore.ieee.org/xpl/tocresult.jsp?isnumber=5410131>
doi: 10.1109/TIE.2015.2499719
[View at Publisher](#)
-
- 41 Moore, K. L.
(1993) *Iterative learning control for deterministic systems*. Cited 678 times.
London: Springer London
-
- 42 Sutyasadi, P., Parnichun, M.
Trotting control of a quadruped robot using PID-ILC
(2015) *IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society*, art. no. 7392784, pp. 4400-4405. Cited 7 times.
ISBN: 978-147991762-4
doi: 10.1109/IECON.2015.7392784
[View at Publisher](#)
-
- 43 Maneetham, D., Sutyasadi, P.
Controlling a knee CPM machine using PID and iterative learning control algorithm ([Open Access](#))
(2020) *Telkomnika (Telecommunication Computing Electronics and Control)*, 18 (2), pp. 1047-1053.
http://journal.uad.ac.id/index.php/TELKOMNIKA/article/download/14876/pdf_1412
doi: 10.12928/TELKOMNIKA.V18I2.14876
[View at Publisher](#)

□ 44 Estakhrouieh Rezaei, M., Gharaveisi, A.
Optimal iterative learning control design for generator voltage regulation system ([Open Access](#))
(2013) *Turkish Journal of Electrical Engineering and Computer Sciences*, 21 (SUPPL. 1), pp. 1909-1919. Cited 8 times.
<http://journals.tubitak.gov.tr/elektrik/issues/elk-13-21-sup.1/elk-21-sup.1-7-1203-19.pdf>
doi: 10.3906/elk-1203-19
[View at Publisher](#)

□ 45 Bovi, G., Rabuffetti, M., Mazzoleni, P., Ferrarin, M.
A multiple-task gait analysis approach: Kinematic, kinetic and EMG reference data for healthy young and adult subjects
(2011) *Gait and Posture*, 33 (1), pp. 6-13. Cited 246 times.
doi: 10.1016/j.gaitpost.2010.08.009
[View at Publisher](#)

□ 46 Kaltjob, P. O. J.
(2021) *Control of mechatronic systems: model-driven design and implementation guidelines*. Cited 2 times.
West Sussex: John Wiley & Sons

□ 47 Salkind, N. J., Frey, B. B., Dougherty, D. M., Teasdale, K. R., Hill-Kapturczak, N.
(2010) *Encyclopedia of research design*. Cited 1194 times.
Thousand Oaks, California: SAGE Publications

🔍 Maneetham, D.; Department of Mechatronics Engineering, Rajamangala University of Technology Thanyaburi, Amphoe Khlong Luang, Tambon Khlong Hok, Pathum Thani, Thailand;
email:dechrit_m@rmutt.ac.th
© Copyright 2022 Elsevier B.V., All rights reserved.

About Scopus

- What is Scopus
- Content coverage
- Scopus blog
- Scopus API
- Privacy matters

Language

- 日本語版を表示する
- 查看简体中文版本
- 查看繁體中文版本
- Просмотр версии на русском языке

Customer Service

- Help
- Tutorials
- Contact us

ELSEVIER

[Terms and conditions ↗](#) [Privacy policy ↗](#)

Copyright © Elsevier B.V. ↗. All rights reserved. Scopus® is a registered trademark of Elsevier B.V.
We use cookies to help provide and enhance our service and tailor content. By continuing, you agree to the use of cookies ↗.



also developed by scimago:

 SCIMAGO INSTITUTIONS RANKINGS

SJR

Scimago Journal & Country Rank

Enter Journal Title, ISSN or Publisher Name 

[Home](#) [Journal Rankings](#) [Country Rankings](#) [Viz Tools](#) [Help](#) [About Us](#)

International Journal of Electrical and Computer Engineering

COUNTRY	SUBJECT AREA AND CATEGORY	PUBLISHER	H-INDEX
Indonesia  Universities and research institutions in Indonesia	Computer Science └ Computer Science (miscellaneous) Engineering └ Electrical and Electronic Engineering	Institute of Advanced Engineering and Science (IAES)	26
PUBLICATION TYPE	ISSN	COVERAGE	INFORMATION
Journals	20888708	2014-2021	Homepage How to publish in this journal ijece@iaesjournal.com

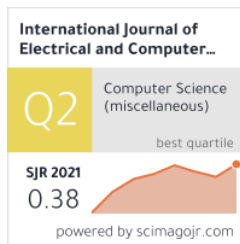
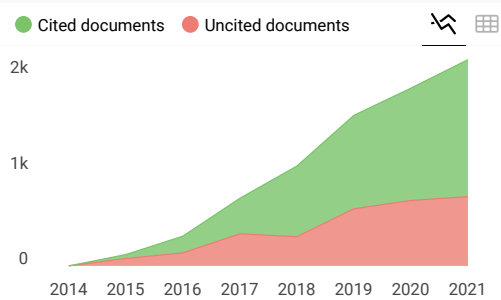
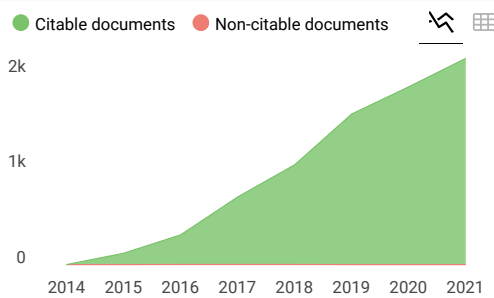
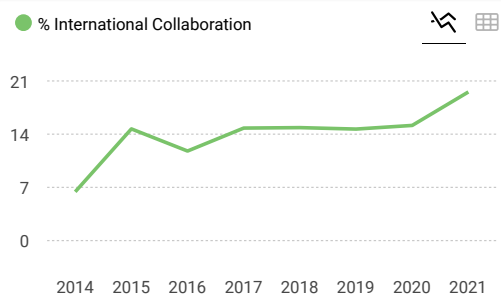
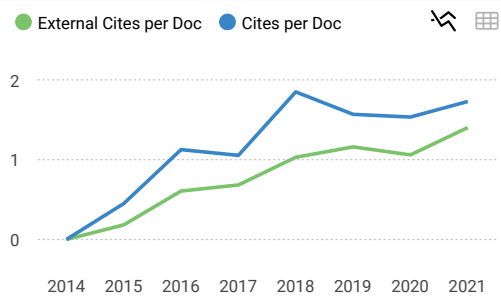
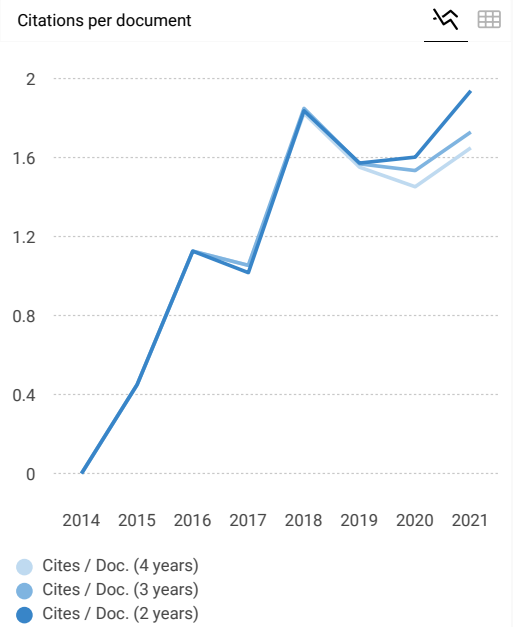
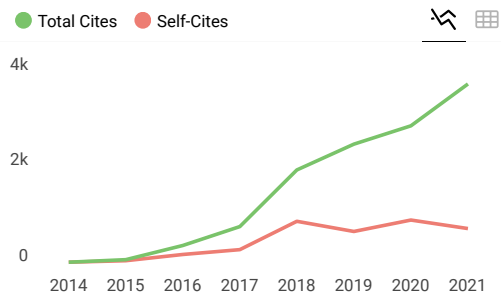
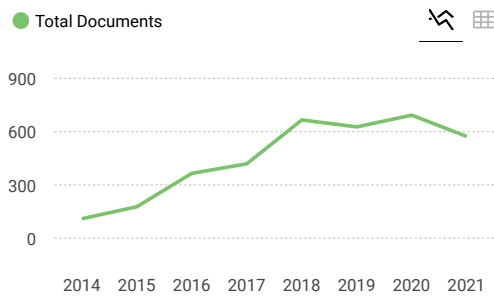
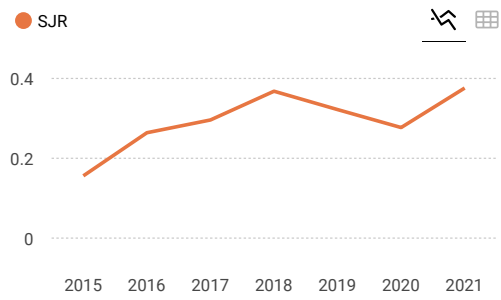
SCOPE

International Journal of Electrical and Computer Engineering (IJECE) is the official publication of the Institute of Advanced Engineering and Science (IAES). The journal is open to submission from scholars and experts in the wide areas of electrical, electronics, instrumentation, control, telecommunication and computer engineering from the global world. The journal publishes original papers in the field of electrical, computer and informatics engineering which covers, but not limited to, the following scope: -Electronics: Electronic Materials, Microelectronic System, Design and Implementation of Application Specific Integrated Circuits (ASIC), VLSI Design, System-on-a-Chip (SoC) and Electronic Instrumentation Using CAD Tools, digital signal & data Processing, , Biomedical Transducers and instrumentation, Medical Imaging Equipment and Techniques, Biomedical Imaging and Image Processing, Biomechanics and Rehabilitation Engineering, Biomaterials and Drug Delivery Systems; -Electrical: Electrical Engineering Materials, Electric Power Generation, Transmission and Distribution, Power Electronics, Power Quality, Power Economic, FACTS, Renewable Energy, Electric Traction, Electromagnetic Compatibility, High Voltage Insulation Technologies, High Voltage Apparatuses, Lightning Detection and Protection, Power System Analysis, SCADA, Electrical Measurements; -Telecommunication: Modulation and Signal Processing for Telecommunication, Information Theory and Coding, Antenna and Wave Propagation, Wireless and Mobile Communications, Radio Communication, Communication Electronics and Microwave, Radar Imaging, Distributed Platform, Communication Network and Systems, Telematics Services and Security Network; -Control[...] -Computer and Informatics[...]

 Join the conversation about this journal

FIND SIMILAR JOURNALS ?

1 Indonesian Journal of Electrical Engineering and IDN	2 Indonesian Journal of Electrical Engineering and IDN	3 Telkomnika (Telecommunication IDN	4 Bulletin of Electrical Engineering and Inform IDN
56%	46%	41%	35%
similarity	similarity	similarity	similarity



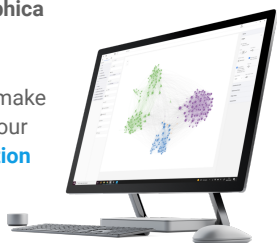
← Show this widget in your own website

Just copy the code below and paste within your html code:

```
<a href="https://www.scimagojr.com/journalsearch.php?q=21100373959&tip=...">
```



Explore, visually communicate and make sense of data with our [new data visualization tool](#).





International Journal of Electrical and Computer Engineering (IJECE)

<http://ijece.iaescore.com> | ISSN 2088-8708, e-ISSN 2722-2578






[HOME](#)
[ABOUT](#)
[LOGIN](#)
[REGISTER](#)
[SEARCH](#)
[CURRENT](#)
[ARCHIVES](#)
[ANNOUNCEMENTS](#)

Home > Vol 13, No 3

International Journal of Electrical and Computer Engineering (IJECE)

International Journal of Electrical and Computer Engineering (IJECE), ISSN 2088-8708, e-ISSN 2722-2578 is an official publication of the Institute of Advanced Engineering and Science (IAES). The IJECE is an international open access refereed journal that has been published online since 2011. The IJECE is open to submission from scholars and experts in the wide areas of electrical, electronics, instrumentation, control, telecommunication, and computer engineering from the global world, and publishes reviews, original research articles, and short communications. This journal is indexed and abstracted by **SCOPUS** (Elsevier), **SCImago Journal Rank (SJR)**, and in Top Databases and Universities. Now, this journal has **SNIP: 0.688**; **SJR: 0.376**; **CiteScore: 3.2**; **Q2 on Computer Science** and **Q3 on Electrical & Electronics Engineering**. Our aim is to provide an international forum for scientists and engineers to share research and ideas, and to promote the crucial field of electrical & power engineering, circuits & electronics, power electronics & drives, automation, instrumentation & control engineering, digital signal, image & video processing, telecommunication system & technology, computer science & information technology, internet of things, big data & cloud computing, and artificial intelligence & soft computing.

IJECE uses a rolling submission process, allowing authors to submit at any time during the year without time restraints.



IJECE | International Journal of Electrical & Computer Engineering
Ongoing Issue: Vol. 13 No. 2 – April 2023

Indexed and abstracted by Scopus (coverage years: 2014 to present), SCImago Journal Rank, and in top databases and universities

Published 6 times in a year: February, April, June, August, October, December

Open Journal System: ijece.iaescore.com

Published by Institute of Advanced Engineering and Science and Intelektual Pustaka Media Utama

Scopus Journal Metrics (2023):
SJR: 0.376 | SNIP: 0.688 | CiteScore: 3.2

Rank within the category: Computer Science—General Computer Science
Quartile: Q2 | CiteScore percentile: 66% | CiteScore rank: 77 out of 231

Rank within the category: Engineering—Electrical and Electronic Engineering
Quartile: Q3 | CiteScore percentile: 53% | CiteScore rank: 328 out of 708

Sections:

- ✓ Electrical and Power Engineering
- ✓ Circuits and Electronics
- ✓ Power Electronics and Drives
- ✓ Automation, Instrumentation and Control Engineering
- ✓ Digital Signal, Image and Video Processing
- ✓ Telecommunication System and Technology
- ✓ Computer Science and Information Technology
- ✓ Artificial Intelligence and Soft Computing
- ✓ Internet of Things, Big Data and Cloud Computing



Authors must strictly follow [the guide for authors](#). Please read [these instructions](#) carefully and follow them strictly. In this way you will help ensure that the review and publication of your paper is as efficient and quick as possible. The editors reserve the right to reject manuscripts that are not in accordance with these instructions. No changes in the author list will be permitted after a manuscript has been accepted.

The IJECE is published bi-monthly (Feb, Apr, Jun, Aug, Oct, Dec).

Contact us by e-mail: ijece@iaesjournal.com

Announcements

IJECE does not accept any papers suggestion from conference organizers

Dear Sir/Madam,

Due to huge regular papers submission, we apologize that our journal does not accept any papers suggestion from other conference organizers. We sincerely apologize for any inconvenience. Critical suggestions are welcome for improvement of the contents and journal policies.

Your attention and cooperation is very highly appreciated.

Best Regards,
IJECE Editorial Office

Posted: 2020-06-01

[More...](#)

[More Announcements...](#)

Vol 13, No 3: June 2023

Table of Contents

[Optimization and fault diagnosis of 132 kV substation low-voltage system using electrical transient analyzer program](#)
Mohammed Kareem Mohammed, Mohammed Qasim Taha, Firas Fadhil Salih, Falah Noori Saeed

[PDF](#)
2375-2383

[Simultaneous network reconfiguration and capacitor allocations using a novel dingo optimization algorithm](#)
Samson Oladayo Ayanlade, Abdulrasaq Jimoh, Emmanuel Idowu Ogunwale, Abdullahi Aremu, Abdulsamad Bolakale Jimoh, Dolapo Eniola Owolabi

[PDF](#)
2384-2395

USER

Username

Password

☐ Remember me

[Login](#)

CITATION ANALYSIS

- Academia.edu
- Dimensions
- Google Scholar
- Scimagojr
- Scholar Metrics
- Scilit
- Scinapse
- Scopus

QUICK LINKS

- Editorial Boards
- Abstracting and Indexing
- Focus and Scope
- Author Guideline
- **Online Submission**
- Publication Ethics
- The Best Journal
- Contact Us

JOURNAL CONTENT

Search

Search Scope

Browse

- By Issue
- By Author
- By Title

INFORMATION

- For Readers
- For Authors
- For Librarians

[Home](#) > [About the Journal](#) > **Editorial Team**

Editorial Team

Editor-in-Chief

[Prof. nzw. dr hab. inż. Lech M. Grzesiak](#), Warsaw University of Technology, Poland

Associate Editors

[Prof. Dr. Abdullah M. Ilyasu](#), Tokyo Institute of Technology, Japan and Prince Sattam Bin Abdulaziz University, Saudi Arabia
[Prof. Dr. Addison Salazar](#), Universidad Politécnica de Valencia, Spain
[Prof. Dr. Ahmed Attiya](#), Electronics Research Institute of Cairo, Egypt
[Prof. Dr. Angela Amphawan](#), Sunway University, Malaysia
[Prof. Dr. Aniello Castiglione](#), University of Naples Parthenope, Italy
[Prof. Dr. Fateh Krim](#), University of Sétif 1, Algeria
[Prof. Dr. Faycal Djeflal](#), University of Batna 2, Algeria
[Prof. Dr. Felix Albu](#), Universitatea Valahia din Targoviste, Romania
[Prof. Dr. Geetam Singh Tomar](#), University of Kent, United Kingdom
[Prof. Dr. Jia-Chin Lin](#), National Central University, Taiwan
[Prof. Dr. José Alfredo Ferreira Costa](#), Universidade Federal do Rio Grande do Norte, Brazil
[Prof. Dr. Krzysztof Szczypiorski](#), Warsaw University of Technology, Poland
[Prof. Dr. Mihaela M. Albu](#), Politehnica University of Bucharest, Romania
[Prof. Dr. Nidhal Bouaynaya](#), Rowan University, Glassboro, United States
[Prof. Dr. Nik Rumzi Nik Idris](#), Universiti Teknologi Malaysia, Malaysia
[Prof. Dr. Sayed M. El-Rabaie](#), Minufiya University, Egypt
[Prof. ing. Salvatore Favuzza, Ph.D.](#), University of Palermo, Italy
[Prof. Ezra Morris Gnanamuthu](#), Universiti Tunku Abdul Rahman, Malaysia
[Prof. Domenico Ciuonzo](#), University of Naples Federico II, Italy
[Prof. Hamidah Ibrahim](#), Universiti Putra Malaysia, Malaysia
[Prof. Paolo Visconti](#), Università del Salento, Italy
[Prof. Peng Zhang](#), Stony Brook University, United States
[Prof. Ranathunga Arachchilage Ruwan Chandra Gopura](#), University of Moratuwa, Sri Lanka
[Assoc. Prof. Dr. Ashkan Sami](#), Shiraz University, Iran, Islamic Republic of
[Assoc. Prof. Dr. Chatchawal Wongchoosuk](#), Kasetsart University, Thailand
[Assoc. Prof. Dr. Chau Yuen](#), Singapore University of Technology and Design, Singapore
[Assoc. Prof. Dr. Giovanni Pau](#), Kore University of Enna, Italy
[Assoc. Prof. Dr. Jaime Lloret Mauri](#), Universitat Politècnica de Valencia, Spain
[Assoc. Prof. Dr. Jinsong Wu](#), Universidad de Chile, Chile
[Prof. Dr. Ke-Lin Du](#), Concordia University, Canada
[Assoc. Prof. Dr. Larbi Boubchir](#), University of Paris 8, France
[Assoc. Prof. Dr. Ming-Fong Tsai](#), National United University, Taiwan
[Assoc. Prof. Ts. Dr. Mohd Ashraf Ahmad](#), Universiti Malaysia Pahang, Malaysia
[Prof. Dr. Naci Genc](#), Yalova University, Turkey
[Assoc. Prof. Dr. Sunday Olatunji](#), Imam Abdulrahman Bin Faisal University, Saudi Arabia
[Assoc. Prof. Dr. Winai Jaikla](#), King Mongkut's Institute of Technology Ladkrabang, Thailand
[Assoc. Prof. Dr. Wudhichai Assawinchaichote](#), King Mongkut's University of Technology Thonburi, Thailand
[Assoc. Prof. Dr. Y. V. Pavan Kumar](#), VIT-AP University, Amaravati, India
[Asst. Prof. Dr. Luca Cassano](#), Politecnico di Milano, Italy
[Dr. Brij Bhooshan Gupta](#), Asia University: Taichung, Taiwan, India
[Dr. Candid Reig](#), University of Valencia, Spain
[Dr. Chin Hsia](#), National Central University, Taiwan, Province of China
[Dr. Chrysovalantou Zigou](#), Technological Educational Institute of Thessaloniki, Greece, Greece
[Dr. Diego Bellan](#), Politecnico di Milano, Italy
[Dr. George Suciu](#), University Politehnica of Bucharest, Romania
[Dr. Harikumar Rajaguru](#), Bannari Amman Institute of Technology, India
[Dr. Haruna Chiroma](#), University of Hafr Al Batin, Saudi Arabia, Nigeria
[Dr. Imran Shafique Ansari](#), King Abdullah University of Science and Technology (KAUST), Saudi Arabia, Qatar
[Dr. Khairulmizam Samsudin](#), Universiti Putra Malaysia, Malaysia
[Dr. Jyoteesh Malhotra](#), Guru Nanak Dev University, India, India
[Dr. Makram Abdulmuttaleb Fakhry](#), University of Technology, Baghdad, Iraq
[Dr. Mohamed Djendi](#), Université Saad Dahlab de Blida, Algeria
[Dr. Mohammed Hosny](#), University of New South Wales, Australia, Australia
[Dr. Nicola Ivan Giannoccaro](#), University of Salento, Italy
[Dr. Pascal Lorenz](#), University of Haute Alsace, France
[Dr. Payam Teimourzadeh Baboli](#), OFFIS - Institute for Information Technology, Germany
[Dr. Po-Chun Huang](#), Yuan Ze University, Taiwan, Province of China
[Dr. Samir Ladaci](#), Polytechnic School of Algiers, Algeria, Algeria
[Dr. Santhanakrishnan Anand](#), New York Institute of Technology, United States
[Dr. Sorin Ioan Deaconu](#), Politehnica University Timisoara, Romania
[Dr. Tossapon Boonogon](#), Aberystwyth University, United Kingdom, Thailand
[Dr. Vicente Garcia Diaz](#), University of Oviedo, Spain
[Dr. Youssef Errami](#), Universiti Tun Hussein Onn Malaysia, Malaysia, Morocco

Editorial Board Members

[Prof. Dr. Abdel Ghani Aissaoui](#), Djillali Liabes University, Sidi-Bel-Abbès, Algeria, Algeria
[Prof. Dr. Abdelhamid Benaini](#), Normandy University, France
[Prof. Dr. Ahmad Saudi Samosir](#), Universitas Lampung, Indonesia
[Prof. Chia-Hung Wang](#), Fujian University of Technology, China
[Prof. Dr. Jun Ma](#), Lanzhou University of Technology, China
[Prof. Dr. Kewen Zhao](#), Qiongzhou University, China
[Prof. Dr. Panagiotis Varzakas](#), University of Thessaly, Greece
[Prof. Dr. Valeri M. Mladenov](#), Technical University of Sofia, Bulgaria
[Prof. univ.dr.ing. Radu A. Vaslu](#), Politehnica University of Timisoara, Romania
[Prof. Dr. Raj Senani](#), Netaji Subhas University of Technology, India
[Prof. Dr. Zoran Bojkovic](#), University of Belgrade, Serbia
[Assoc. Prof. Farrokh Attarzadeh, Ph.D.](#), University of Houston, United States
[Assoc. Prof. Dr. Kottakkaran Sooppy Nisar](#), Prince Sattam bin Abdulaziz University, Saudi Arabia
[Assoc. Prof. Dr. Lisandro Lovisolo](#), Universidade do Estado do Rio de Janeiro, Brazil
[Assoc. Prof. Dr. Mohammad Facta](#), Universitas Diponegoro (UNDIP), Indonesia
[Prof. Dr. Mohammed Issam Younis](#), University of Baghdad, Iraq
[Assoc. Prof. Dr. Nabil Neggaz](#), Université des Sciences et de la Technologie d'Oran Mohamed Boudiaf, Algeria
[Dr. Achinta Baldya](#), Mizoram University, India
[Dr. Ali Hakam](#), General Electric, United Arab Emirates
[Dr. Alivelu Manga Parimi](#), Birla Institute of Technology and Science (BITS), Pilani, India
[Dr. Amit Prakash Singh](#), Guru Gobind Singh Indraprastha University, India
[Dr. Arafat Al-Dweik](#), Khalifa University, United Arab Emirates
[Dr. Athanasios Salamanis](#), Information Technologies Institute, Greece
[Dr. Badrul Hisham Ahmad](#), Universiti Teknikal Malaysia Melaka, Malaysia
[Dr. Brijesh B. Mehta](#), Automaton AI Infosystem Pvt Ltd, India
[Dr. Ceren Kaya](#), Zonguldak Bülent Ecevit University, Turkey
[Dr. Deris Stiawan, CjEH, CJHFI](#), Universitas Sriwijaya, Indonesia

USER

Username
Password
☐ Remember me
[Login](#)

CITATION ANALYSIS

- Academia.edu
- Dimensions
- Google Scholar
- Scimagojr
- Scholar Metrics
- Scilit
- Scinapse
- Scopus

QUICK LINKS

- Editorial Boards
- Abstracting and Indexing
- Focus and Scope
- Author Guideline
- **Online Submission**
- Publication Ethics
- The Best Journal
- Contact Us

JOURNAL CONTENT

Search
Search Scope
All

Browse

- By Issue
- By Author
- By Title

INFORMATION

- For Readers
- For Authors
- For Librarians

[Dr. Hanane Arahmane](#), CEA, LIST, Laboratoire Capteurs Architectures Electroniques, 91191 Gif-sur-Yvette, France, Morocco
[Dr. Hedieh Sajedi](#), University of Tehran, Iran, Islamic Republic of
[Dr. Hidayat Zainuddin](#), Universiti Teknikal Malaysia Melaka, Malaysia
[Dr. Jiashen Teh](#), Universiti Sains Malaysia, Malaysia
[Dr. Jingi Zhu](#), Tianjin Normal University, China
[Dr. Jun-Cheol Jeon](#), Kumoh National Institute of Technology, Korea, Republic of
[Dr. Junjie Lu](#), Broadcom Corp., United States
[Dr. Koushik Dutta](#), University of Central Florida: Orlando, Florida, United States, India
[Dr. Laith Abualigah](#), Al-Ahliyya Amman University: Amman, Yordania, Jordan
[Dr. Laura Garcia-Hernández](#), CMR Institute of Technology: Bangalore, Karnataka, India, Spain
[Dr. M. Bhargav Sri Venkatesh](#), Indian Institute of Technology Bombay, India
[Dr. Mehrdad Ahmadi Kamarposhti](#), Jouybar Branch, Islamic Azad University, Iran, Islamic Republic of
[Dr. Meng Li](#), The Hong Kong Polytechnic University, China
[Dr. Mohammad Abdullah](#), University Tun Hussein Onn Malaysia, Malaysia
[Dr. Mohammad Alibakhshikenari](#), University of Rome "Tor Vergata", Italy
[Dr. Mohammad Yazdani-Asrami](#), University of Glasgow: Glasgow, Inggris Raya, United Kingdom
[Dr. Mowafak K. Mohsen](#), University of Kerbala, Iraq
[Dr. Munawar A. Riyadi](#), Universitas Diponegoro, Indonesia
[Dr. Nafarizal Nayan](#), Universiti Tun Hussein Onn Malaysia, Malaysia
[Dr. Nizam Uddin Ahamed](#), University of Pittsburgh: Pittsburgh, PA, Amerika Serikat, Canada
[Dr. Nizam Uddin Ahamed](#), University of Pittsburgh: Pittsburgh, PA, Amerika Serikat, Malaysia
[Dr. Nuri Yilmazer](#), Texas A&M University-Kingsville, United States
[Dr. Omar Naifar](#), University of Sfax, Tunisia
[Dr. Omer Saleem](#), National University of Computer and Emerging Sciences, Pakistan
[Dr. Ornella Juliana Piccinni](#), Istituto Nazionale di Fisica Nucleare, Italy
[Dr. P. Gopi Krishna](#), K L University, India
[Dr. Prabira Kumar Sethy](#), Sambalpur University, India
[Dr. Rajvikram Madurai Elavarasan](#), Thiagarajar College of Engineering, Madurai, TAMIL NADU, India, India
[Dr. Ranjit Kumar Barai](#), Jadavpur University, India
[Dr. Sandipann P. Narote](#), Government Women Residence Polytechnic, India
[Dr. Shadi A. Alboon](#), Yarmouk University, Jordan
[Dr. Teddy Surya Gunawan](#), Electrical and Computer Engineering Department Faculty of Engineering International Islamic University Malaysia, Malaysia
[Dr. Uei-Ren Chen](#), Hsiuping University of Science and Technology, Taiwan
[Dr. W. Mansor](#), Universiti Teknologi MARA, Malaysia

[International Journal of Electrical and Computer Engineering \(IJECE\)](#)

p-ISSN 2088-8708, e-ISSN 2722-2578

- By Title

INFORMATION

- For Readers
- For Authors
- For Librarians

HOME

ABOUT

LOGIN

REGISTER

SEARCH

CURRENT

ARCHIVES

ANNOUNCEMENTS

Home > [Archives](#) > **Vol 12, No 6**

Vol 12, No 6

December 2022

DOI: <http://doi.org/10.11591/ijece.v12i6>

Table of Contents

International Journal of Electrical and Computer Engineering: a bibliometric analysis	PDF
Yeison Alberto Garcés-Gómez, Vladimir Henao-Céspedes	5667-5673
Recursive convex approximations for optimal power flow solution in direct current networks	PDF
Jauder Alexander Ocampo-Toro, Oscar Danilo Montoya, Luis Fernando Grisales-Noreña	5674-5682
Dual techniques of load shedding and capacitor placement considering load models for optimal distribution system	PDF
Ali Nasser Hussain, Waleed Khalid Shakir Al-Jubori	5683-5696
Electric and magnetic field calculation software in transmission lines	PDF
Luis Imbachi Guerrero, Fredy Jiménez Rubio, Mario Rodríguez Barrera, Diego Giral-Ramírez	5697-5706
Application of artificial intelligence in early fault detection of transmission line-a case study in India	PDF
Prashant P. Mawle, Gunwant A. Dhokane, Prakash G. Burade	5707-5716
Comparative analysis of evolutionary-based maximum power point tracking for partial shaded photovoltaic	PDF
Prisma Megantoro, Hafidz Faqih Aldi Kusuma, Lilik Jamilatul Awal, Yusrizal Afif, Dimas Febriyan Priambodo, Pandi Vigneshwaran	5717-5729
Optimization of the structure of filter-compensating devices in networks with powerful non-linear power consumers based on fuzzy logic	PDF
Evgeniy Vitalievich Zhilin, Dmitriy Aleksandrovich Prasol, Nikita Yurievich Savvin	5730-5737
Analytical transformations software for stationary modes of induction motors and electric drives	PDF
Mohamed Zaidan Qawaqzeh, Oleksandr Miroshnyk, Aleksandr Osichev, Andrii Tkachenko, Dmytro Danylchenko	5738-5753
Comparison analysis of different classification methods of power quality disturbances	PDF
	5754-5764

Nur Adrinna Shafiq Zakaria, Dalila Mat Said, Norzanah Rosmin, Nasarudin Ahmad, Mohamad Shazwan Shah Jamil, Sohrab Mirsaeidi

Modified sunflower optimization for network reconfiguration and distributed generation placement	PDF 5765-5774
Thuan Thanh Nguyen, Ngoc Anh Nguyen, Thanh Long Duong, Thanh Quyen Ngo, Thanhquy Bach	
Maximum power point tracking based on improved spotted hyena optimizer for solar photovoltaic	PDF 5775-5788
Muhammad Farizky Alvianandy, Novie Ayub Windarko, Bambang Sumantri	
A new windings design for improving single-phase induction motor performance	PDF 5789-5798
Zuriman Anthony, Erhaneli Erhaneli, Yusreni Warmi, Zulkarnaini Zulkarnaini, Anggun Anugrah, Sepannur Bandri	
An efficient scanning algorithm for photovoltaic systems under partial shading	PDF 5799-5807
Mohamed Bahri, Mohamed Talea, Hicham Bahri, Mohamed Aboulfatah	
Anomalies detection for smart-home energy forecasting using moving average	PDF 5808-5820
Jesmeen Mohd Zebara Hoque, Gajula Ramana Murthy, Jakir Hossen, Jaya Ganesan, Azlan Abd Aziz, Chy. Mohammed Tawsif Khan	
Comparative detection and fault location in underground cables using Fourier and modal transforms	PDF 5821-5839
Vahdat Nazerian, Mohammad Esmail Zakerifar, Mahmoud Zadehbagheri, Mohammad Javad Kiani, Tole Sutikno	
Range-enhanced packet classification to improve computational performance on field programmable gate array	PDF 5840-5847
Anita Ponnuswamy, Manju Devi	
Grouping based radio frequency identification anti-collision protocols for dense internet of things application	PDF 5848-5860
Nnamdi H. Umelo, Nor K. Noordin, Mohd Fadlee A. Rasid, Tan K. Geok, Fazirulhisyam Hashim	
Simulation and performance analysis of self-powered piezoelectric energy harvesting system for low power applications	PDF 5861-5871
Mohankumar Venugopal, Govindanayakanapalya Venkatagiriappa Jayaramaiah	
Higher chromatic rendition with Cr³⁺-doped yellow Y₃Al₅O₁₂:Ce³⁺ for double-layer remote phosphor white-light-emitting diodes	PDF 5872-5879
Dieu An Nguyen Thi, Phuc Dang Huu, Thuy Hang Nguyen Thi	
Auxetic material in biomedical applications: a systematic review	PDF 5880-5889
Andrés Diaz Melgarejo, Jose Luis Ramírez, Astrid Rubiano	
A design of soft-gauge for elevator vibration analysis based on low-cost accelerometer MMA7361L and LabVIEW	PDF 5890-5899
Chi Nguyen Van, Lam Huong Duong, Yen Duy Dao, Thanh Ngo Phuong	
Conducted emission investigation of infant incubator heating control mode	PDF 5900-5910
Khusnul Khotimah, Yoppy Yoppy, Muhammad Imam Sudrajat, Vera Permatasari, Elvina Trivida, Tyas Ari Wahyu Wijarnoko	

A self-balancing platform on a mobile car	PDF
Bushra Amer Tawfeeq, Maher Yahya Salloom, Ahmed Alkamachi	5911-5922
Three-phase four-wire shunt hybrid active power filter model with model predictive control in imbalance distribution networks	PDF
Asep Andang, Rukmi Sari Hartati, I Bagus Gede Manuaba, I Nyoman Satya Kumara	5923-5937
Energy management for hybrid electric vehicles using rule based strategy and PI control tuned by particle swarming optimization algorithm	PDF
Maher Al-Flehawee, Auday Al-Mayyahi	5938-5949
Controlling the half-step mode operation of the variable reluctance stepper motor by using Mamdani type of fuzzy logic controller	PDF
Mustafa A. Mhawesh, Ahmed S. Kashkool	5950-5957
3D printing part orientation optimization: discrete approximation of support volume	PDF
Juan C. Guacheta Alba, Sebastian Gonzalez Garzon, Diego A. Nunez, Mauricio Mauleudoux, Oscar F. Aviles	5958-5966
Control of robot-assisted gait trainer using hybrid proportional integral derivative and iterative learning control	PDF
Elang Parikesit, Dechrit Maneetham, Petrus Sutiyasadi	5967-5978
Optimal trajectory tracking control for a wheeled mobile robot using backstepping technique	PDF
Said Fadlo, Abdelhafid Ait Elmahjoub, Nabila Rabbah	5979-5987
Estimation of water momentum and propeller velocity in bow thruster model of autonomous surface vehicle using modified Kalman filter	PDF
Hendro Nurhadi, Mayga Kiki, Dieky Adzkiya, Teguh Herlambang	5988-5997
A survey on bio-signal analysis for human-robot interaction	PDF
Huda Mustafa Radha, Alia Karim Abdul Hassan	5998-6009
Modeling and analysis of field-oriented control based permanent magnet synchronous motor drive system using fuzzy logic controller with speed response improvement	PDF
Parvathy Thampi Mooloor Sahridayan, Raghavendra Gopal	6010-6021
Internet of things implementation and analysis of fuzzy Tsukamoto in prototype irrigation of rice	PDF
Lukman Medriavin Silalahi, Dimas Jatikusumo, Setiyo Budiyanto, Freddy Artadima Silaban, Imelda Uli Vistalina Simanjuntak, Agus Dendi Rochendi	6022-6033
Driving sleepiness detection using electrooculogram analysis and grey wolf optimizer	PDF
Sarah Saadoon Jasim, Alia Karim Abdul Hassan	6034-6044
End-to-end deep auto-encoder for segmenting a moving object with limited training data	PDF
Abdeldjalil Kebir, Mahmoud Taibi	6045-6057
Proposal for a fuzzy logic-based system to determine cardiovascular risk	PDF
Gabriel Elías Chanchí Golondrino, Manuel Alejandro Ospina Alarcón, Wilmar Yesid Campo Muñoz	6058-6067

Control of robot-assisted gait trainer using hybrid proportional integral derivative and iterative learning control

Elang Parikesit¹, Dechrit Maneetham¹, Petrus Sutiyasadi²

¹Department of Mechatronics Engineering, Rajamangala University of Technology Thanyaburi, Thailand

²Mechatronics Department, Faculty of Vocational, Sanata Dharma University, Yogyakarta, Indonesia

Article Info

Article history:

Received Oct 25, 2021

Revised Jul 29, 2022

Accepted Aug 15, 2022

Keywords:

Exoskeleton

Gait trainer

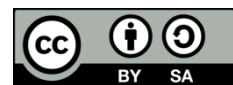
Lower limb

Robotics

ABSTRACT

An inexpensive exoskeleton of the lower limb was designed and developed in this study. It can be used as a gait trainer for persons with lower limb problems. It plays an essential role in lower limb rehabilitation and aid for patients, and it can help them improve their physical condition. This paper proposes a hybrid controller for regulating the lower limb exoskeleton of a robot-assisted gait trainer that uses a proportional integral and derivative (PID) controller combined with an iterative learning controller (ILC). The direct current motors at the hip and knee joints are controlled by a microcontroller that uses a preset pattern for the trajectories. It can learn how to monitor a trajectory. If the trajectory or load is changed, it will be able to follow the change. The experiment showed that the PID controller had the smallest overshoot, and settling time, and was responsible for system stability. Even if there are occasional interruptions, the tracking performance improves with the ILC.

This is an open access article under the [CC BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.



Corresponding Author:

Dechrit Maneetham

Department of Mechatronics Engineering, Rajamangala University of Technology Thanyaburi

Tambon Khlong Hok, Amphoe Khlong Luang, Pathum Thani, Thailand

Email: dechrit_m@rmutt.ac.th

1. INTRODUCTION

The term "cardiovascular disease" refers to a collection of illnesses that include heart disease, brain vascular disease, and diseases of other blood arteries. A kind of cardiovascular disease (CVD) is stroke [1]. Stroke ranks number 5 among all causes of death and the second-leading cause of death behind ischemic heart disease [2]. Neurological injuries, such as strokes and spinal cord injuries, often cause physical ailments that affect a person's ability to walk stroke is a significant disease in Asia, where more than 60% of the world's population lives. Except for a few nations like Japan, stroke deaths are higher in Asia than in Western Europe, America, or Australia [3]. Loss of walking ability often leads to dependence on wheelchairs or other mobility aids such as orthoses. Restoring the ability to walk is one of the main goals of recovery for many with neurological disorders. Various treatments have been used to re-learn motor skills and performance of walking by using robotic devices [4], [5]. There are walking trainers using robots available in the market, but the price is still very high [6]. Frugal Innovation is described as the potential to "do more with less"-that is, to generate considerably more market and social benefit while reducing the use of finite resources like electricity, money, and time [7]. In resource-constrained settings, healthcare providers often devise novel approaches to deliver sufficient treatment to patients. These low-cost yet practical, frugal inventions may have flaws, but they have the potential to make wellness more accessible to everyone [8].

With its high reliability and ease of implementation, proportional integral and derivative (PID) is the most often used controller because of its great dependability and simplicity of installation. However, a

PID-only controller is unsuitable for an exoskeleton robot due to variables such as variations in load, friction, and external interference [9], [10]. On the other hand, there is an iterative learning control algorithm (ILC) that, even though it is excellent at controlling repeated motions, has a significant tracking error and an unclear initial value, making it difficult to use in practice [11], [12]. There are some ideas of using a hybrid controller such as PID-ILC in improving the trajectory of a mechanism [13], but it was never implemented in the lower limb exoskeleton. Majeed *et al.* [14] already used the other types of hybrid controller, proportional derivative (PD) with particle swarm optimization (PSO), for the lower limb exoskeleton. It has better joint tracking performance, but upon the presence of disturbance, its efficacy deteriorates. Meanwhile, Amiri *et al.* [15] used PID with model reference adaptive control (MRAC). The speed and performance are better than PID, but there is an overshoot and gradually returns to the desired position. The goal of this research is to optimize the robot-assisted walking trainer's lower limb exoskeleton's control algorithm by utilizing hybrid PID-ILC to track the reference trajectory even when the lower limb is under varied load (disturbance) without going overshoot.

2. METHOD

2.1. System design

As shown in Figure 1, the fundamental control strategies of robot-assisted gait trainers were covered within a three-level framework that corresponds to the structure and functionality of the human neurological system. Being able to work together or separately, these levels are independent of each other [16]. This research robot of a robot-assisted gait trainer deals with the low level of control.

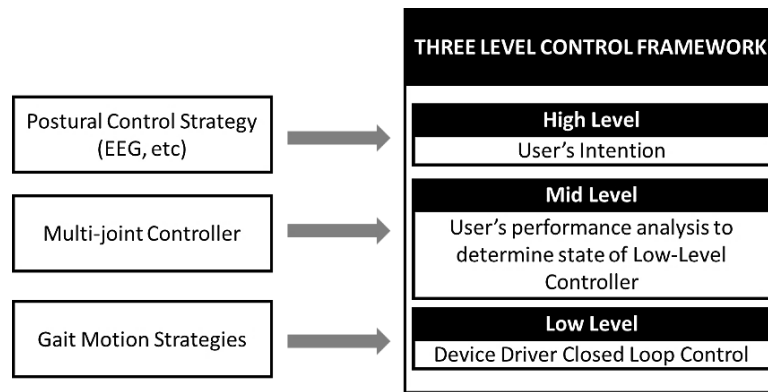


Figure 1. Hierarchical control framework of robot-assisted gait trainer

2.2. The kinematics for lower limb exoskeleton

The lower link exoskeleton is a two-link planar revolute-revolute arm. Figure 2 [17] shows such a 2 revolute (2R) planar manipulator with two revolute-revolute links. The inverse kinematics of a lower limb exoskeleton is similar to that of a planar robot in that it is easier to discover analytically. The tip point's global location is shown in (1).

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} l_1 \sin \theta_1 + l_2 \sin(\theta_1 + \theta_2) \\ l_1 \cos \theta_1 + l_2 \cos(\theta_1 + \theta_2) \end{bmatrix} \quad (1)$$

Therefore:

$$X^2 + Y^2 = l_1^2 + l_2^2 + 2l_1l_2 \cos \theta_2 \quad (2)$$

and:

$$\cos \theta_2 = \frac{X^2 + Y^2 - l_1^2 - l_2^2}{2l_1l_2} \quad (3)$$

$$\theta_2 = \cos^{-1} \frac{X^2 + Y^2 - l_1^2 - l_2^2}{2l_1l_2} \quad (4)$$

Due to their inaccuracy, Arcsin and Arccos are typically avoided. As a result, we use the half-angle formula.

$$\tan^2 \frac{\theta}{2} = \frac{1 - \cos \theta}{1 + \cos \theta} \quad (5)$$

To find θ_2 using an arctan 2 function:

$$\theta_2 = \pm \arctan 1 \sqrt{\frac{(l_1 + l_2)^2 - (X^2 + Y^2)}{(X^2 + Y^2) - (l_1 + l_2)^2}} \quad (6)$$

Square root generates two solutions. Thus, the sign $\pm$ is needed. Based on geometry, the initial joint variable configuration may be determined as (7):

$$\theta_1 = \arctan 2 \frac{Y}{X} + \arctan 2 \frac{l_2 \sin \theta_2}{l_1 + l_2 \cos \theta_2} \quad (7)$$

The following alternate equation can also be used:

$$\theta_1 = \arctan 2 \frac{-X l_2 \sin \theta_2 + Y(l_1 + l_2 \cos \theta_2)}{Y l_2 \sin \theta_2 + X(l_1 + l_2 \cos \theta_2)} \quad (8)$$

when X has a positive or negative sign, the value of θ_1 should be changed by adding or removing π . In addition, the equations can be concatenated as (9).

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} l_1 \sin \theta_1 + l_2 \sin(\theta_1 + \theta_2) \\ l_1 \cos \theta_1 + l_2 \cos(\theta_1 + \theta_2) \end{bmatrix} \quad (9)$$

Therefore, to determine a trigonometric equation for θ_1 :

$$2X l_1 \cos \theta_1 + 2Y l_1 \sin \theta_1 = X^2 + Y^2 + l_1^2 - l_2^2 \quad (10)$$

Additionally, the (11) can be used:

$$l_1 + l_2 \cos \theta_2 = \frac{X^2 + Y^2 + l_1^2 - l_2^2}{2l_1} \quad (11)$$

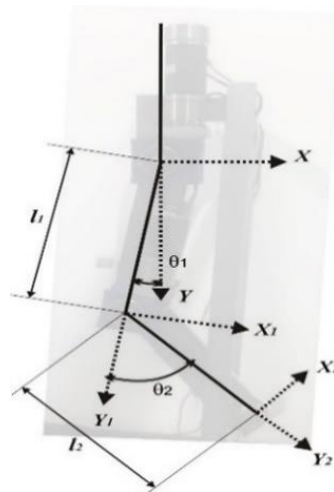


Figure 2. Lower limb exoskeleton kinematics

2.3. Mechanical design

There is a similarity between the human and the produced robotic joint for the knee as shown in Figures 3(a) and 3(b). Flexion and extension and internal and external rotation of a knee are shown in

Figure 3(a) [18]. While the knee part of the exoskeleton of the gait trainer is shown in Figure 3(b). The exoskeleton being developed only uses the sagittal plane as the range of motion (flexion and extension). To protect the user from injury, the range of joint angles is mechanically limited. Table 1 displays the values of hip and knee kinematics [19].

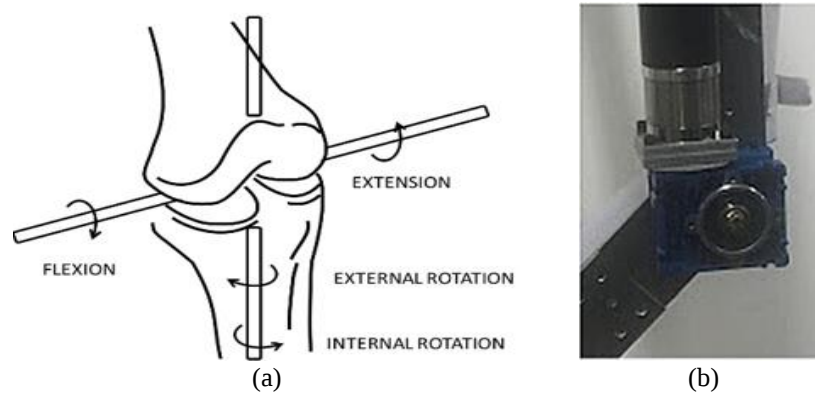


Figure 3. Comparison of (a) the human knee joint compared with (b) the exoskeleton joint

Table 1. Kinematics of hip and knee

	Motion	Range of Motion (degree)	Average Torque (Nm)
Hip	Flexion	100-140	140
	Extension	15-30	120
Knee	Flexion	120-140	140
	Extension	0-10	15

The exoskeleton is made to be as light as possible. It is envisioned as a four-degrees of freedom (DoF) bilateral wearable device with actuators at the joints of the hip and knee. The mechanical drawing of the lower limb exoskeleton can be seen in Figure 4. Aluminum is used in the mechanical structure to accommodate mechanical resistance and reduce weight [20].

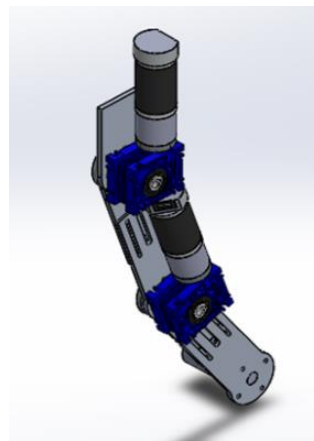


Figure 4. Mechanical drawing of lower limb exoskeleton

The movement equipment was selected according to each joint's tension and force values when walking at a typical speed. Direct current (DC) motors meet the performance criteria for a portable device's small solution. Because exoskeleton joints demand higher torque and lower speeds, DC motors can be connected directly to the gearbox to boost torque and reduce speed [21]. As shown in Figure 5(a) PG56 encoder brushed DC motor is used as the actuator, while Figure 5(b) shows the gearbox that is connected to

DC motor to increase the torque by 50 times. As shown in Figure 6, there are four DC motors to drive four joints in this lower limb exoskeleton), two motors for the left side, and two motors for the right side. The DC servo motors control the joint motors (PG56) using pulse width modulation (PWM) outputs from the microcontroller.



Figure 5. The actuator consists of (a) a PG56 encoder brushed DC motor that is connected to (b) a gearbox with shaft ratio 1:50



Figure 6. Lower limb exoskeleton with hip and knee joints

2.4. PID control

The first PID controller was ship autopilot owned by Elmer Sperry in 1910. Since Ziegler and Nichols [22] developed the methods of PID tuning in 1942, the popularity of the controller has risen even more [23]. Changes are required for three parameters in PID control [24]: the proportional, integral, and derivative. However, the PID control parameter adjustment affects system performance, such as stability and robustness [25]. Classical control theory provides a strong set of study tools to analyze closed-loop systems and build feedback controllers. The reference variable is sometimes referred to as the set point. The PID gain is the sum of the P-term, the I-term, and the D-term. A control action also can be viewed as a combination of integral, proportional, and derivative parts of a mathematical expression. The PID algorithm may be summarized as (12):

$$u(t) = K \left(e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{de(t)}{dt} \right) \quad (12)$$

where y is measured process variable, r is reference variable, u is control signal, e is control error ($e = y_{sp} - y$), K is proportional gain, T_i is integral time, and T_d is derivation time

Several research of PID, hybrid controller [26], and hybrid PID controllers [27]–[30] have been conducted until now that indicated better performance than other types of controllers such as fuzzy controllers [31]. Meanwhile, a hybrid controller such as fuzzy-PID has the benefit of having better system response [32], compared to the traditional PID, provides a lower initial control signal [33], and performs better than other controllers in terms of system robustness as well as parameter variation [34]. In situations when a traditional PID structure with constant coefficients may not perform, another type of PID, sigmoid PID delivers a faster controller response with less overshoot [35].

2.5. Hybrid PID and ILC

The PID feedback controls are ineffective for systems that have both continuous and discrete dynamics. We can use hybrid control for that situation [36]. For instance, we can use PID control combined with ILC. More than a decade of study has gone into ILC, and the work by Arimoto *et al.* [37] is widely cited as the primary source of motivation for research in this field [37]. As the name suggests, ILC is a recurrent process control technique. It is essential for applications exploring trajectory tracking control over a limited interval $[0, T]$. It concentrates on issues where interaction between passes is typically zero but where repetition of a single task allows for performance improvement from task to task [38]. Even in situations where repetitive tasks are done over fixed periods, ILC is an efficient method for improving transient response and tracking performance in the presence of parametric uncertainties and unmodeled dynamics [39], [40]. For a system that executes the same trajectory repeatedly, ILC is a relatively novel control method. Using this technique, we can enhance both transient responsiveness and tracking performance [41]. A modest PID gain should be used in most situations. Especially if the intrinsic frequency of the system is not properly evaluated, high PID gains might cause system vibrations. When the adjusted control signal reaches the intended trajectory, the ILC is utilized to fine-tune it.

There is considerable nonlinearity, strong coupling, and time-varying dynamic characteristics in the lower limb exoskeleton. The mathematical model employed to construct it is ambiguous and may cause system instability. For the most part, iterative learning control does not require any specific models. It is ideal for controlling objects which move in a finite period. The tracking error is modified according to the learning signal to enhance a particular control goal and track the intended trajectory [42], [43]. In brief, because the PID has strong robustness and the ILC has good performance, it is assumed that their combination will have both [44]. Figure 7 depicts a diagram block of hybrid PID-ILC applied to the exoskeleton, where u_j is ILC control signal, k_p is proportional value, k_d is derivative value, k_i is integral value, e_j is error between desired and actual outputs (y_d to y_j), and j is number of iterations

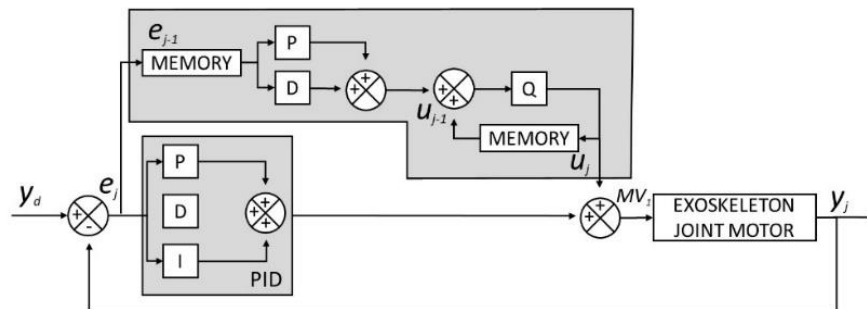


Figure 7. Block diagram of Hybrid PID-ILC applied to an exoskeleton

2.6. Microcontroller and motor driving system

The wiring diagram of the microcontroller and motor driving system is shown in Figure 8. A 24 V lithium-ion battery is used to power the DC motor and electronic circuits of the exoskeleton. Then the switched regulators convert 24 volts DC from the battery to 5 volts to supply the electronic circuits. The gait trajectories are stored in the microcontroller's memory, an Atmel ATmega 328 on the Arduino platform. Each time the microcontroller will send the position data to motor drivers. The BTS7960 High current motor driver h-bridge module will amplify the currents so there will be enough current to drive the DC motors (PG56 DC motors). Each motor can drive a single joint. The encoder will send back the actual position of the joints as the inputs of the microcontroller. Then the microcontroller will compute the voltage value to be sent to driver circuits.

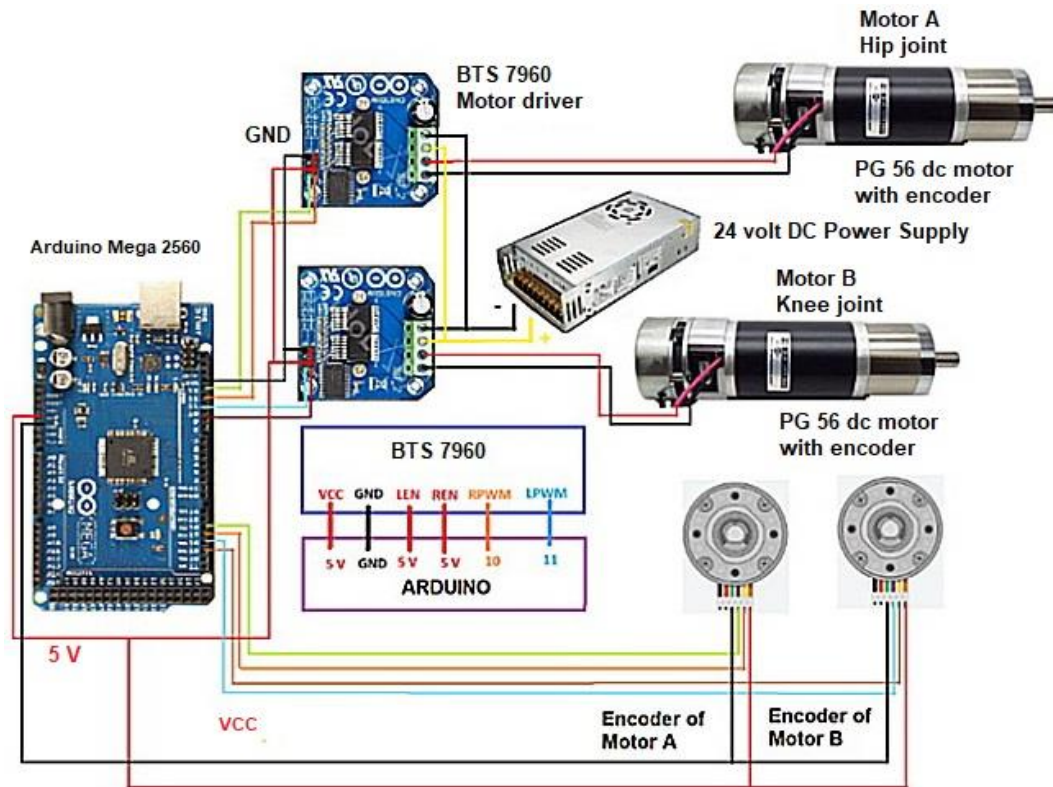


Figure 8. Wiring diagram of microcontroller and motor driving system

3. RESULTS AND DISCUSSION

In this work, a normal gait pattern used as the reference trajectory was provided by previous experiments dataset from healthy subjects [45]. Figures 9 and 10 respectively show the graphs of the flexion and extension movements of hip and knee joints based on that data. Figure 9 shows that the range of hip flexion/extension is from -18 to 25 degrees. While in Figure 10, the range of the knee flexion/extension is from 0 to 60 degrees.

The microcontroller executed data and transferred it to a driver to move the DC motor based on stored trajectory data by utilizing a control algorithm. There are two steps in applying the hybrid PID-ILC algorithm. Firstly, just use the PID control without ILC and make it stable by tuning the PID parameters, K_p , K_i , and K_d . Table 2 [46] can be used for reference for the PID tuning. After the PID response is stable, the ILC learning algorithm can be activated.

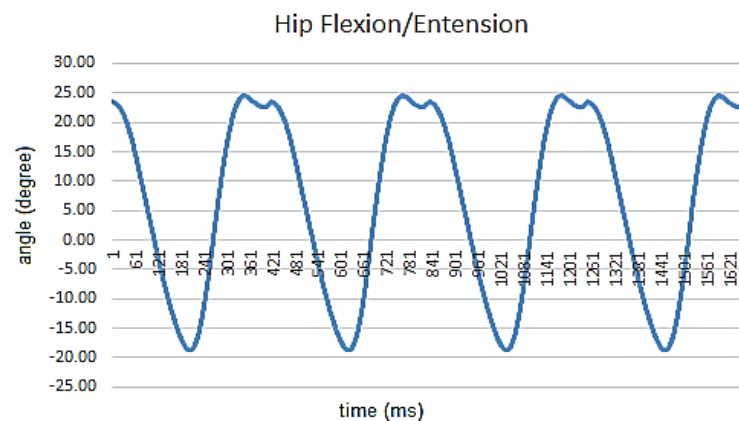


Figure 9. Flexion and extension movements of hip based on the dataset

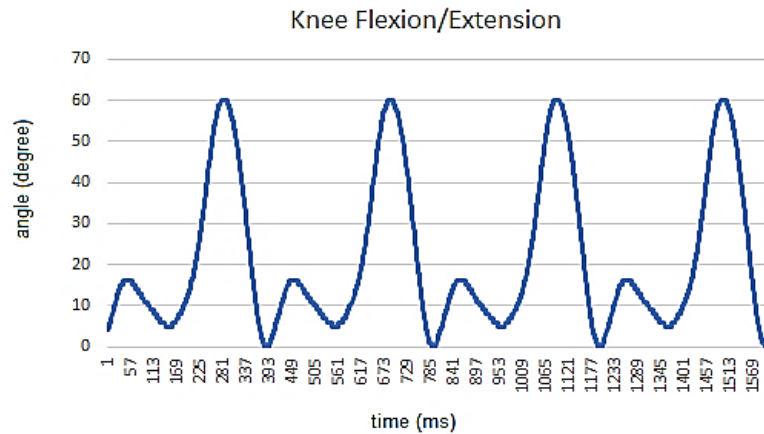


Figure 10. Flexion and extension movements of the knee based on the dataset

Table 2. PID controller tuning parameters

Response	Rise time	Overshoot	Settling time	S-S error
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Decrease
Kd	Small Change	Decrease	Decrease	No Change

In Figures 11 to 14, we can observe the location of the hip and knee joints of the exoskeleton. As illustrated in Figures 11 and 13, PID only results in a significant steady-state error, yet the system remains stable. As shown in Figure 11, the PID-only controller is being used to control hip movement. The exoskeleton moved along with the load from the lower limb. The range of hip flexion/extension is -15 until 20 degrees. The system is stable, but there are steady-state errors between 0 to 10 degrees.

Figure 12 shows the hybrid PID-ILC controller being used to control the hip movement. Still, with the same controller gain and load, there are significant improvements in the performance in the initial move from 0 to 5 degrees. But after more than ten iterations, the steady-state errors can be minimized under 1 degree the range of hip just as the same with the set point.

In Figure 13, the PID-only controller is being used to control knee movement. The exoskeleton moved along with the same load from the lower limb and with the same controller gain. The range of knee flexion/extension is eight until 55 degrees. The system is also stable, but there are steady-state errors between 0 to 10 degrees.

In Figure 14, the hybrid PID-ILC controller is being used to control knee movement. Still, with the same controller gain and load, there are significant improvements in the performance in the initial move from 0 to 10 degrees. But after more than ten iterations, the steady-state errors can be minimized under 1 degree—the range of hip just as the same with the set point. Figures 12 and 14 show that it takes more than ten iterations to achieve the trajectory set point after using hybrid PID-ILC, as illustrated in Figures 12 and 14. The output filtering causes the phase difference. The output is sound, with a low steady-state error rate, according to the results.

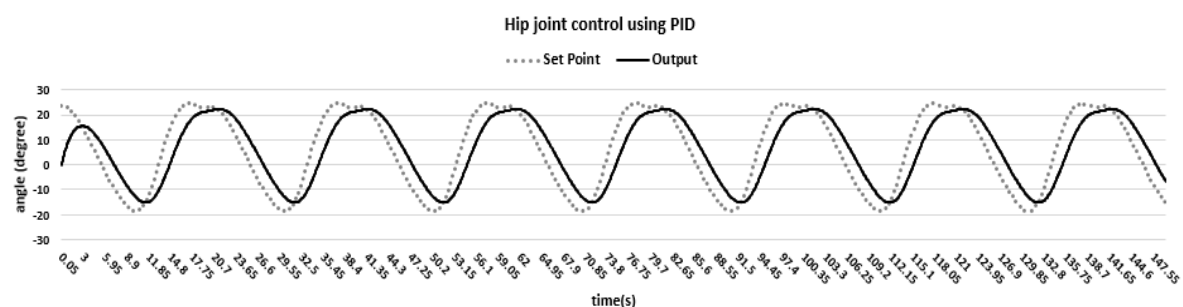


Figure 11. Flexion and extension movements of exoskeleton hip using PID only

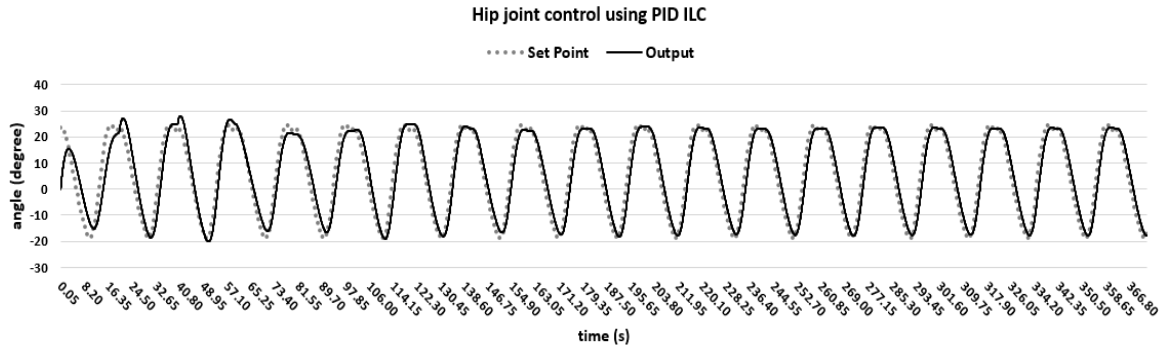


Figure 12. Flexion and extension movements of exoskeleton hip using PID-ILC

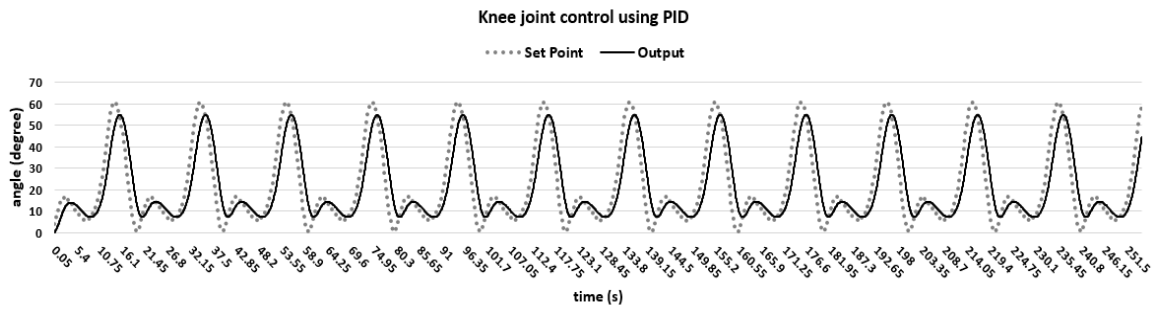


Figure 13. Flexion and extension movements of exoskeleton knee using PID only

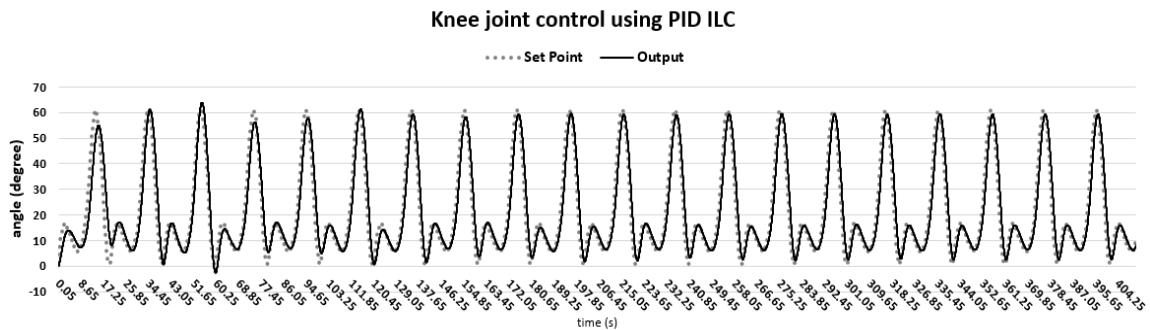


Figure 14. Flexion and extension movements of exoskeleton knee using PID-ILC

Assessment of system performance can be done by measuring or calculating the system's performance index. In this case, the mean square error (MSE) and the root mean square error (RMSE) can be used. The square RMSE is called MSE. The RMSE is a metric that compares the predicted values of a hypothetical model to the actual values [47]. Table 3 shows the numerical analysis comparison of PID and PID-ILC responses, based on the RMSE and MSE. It can be seen that steady-state errors are greatly reduced to 50%. Mean square error can be expressed as:

$$MSE = \frac{\sum_{j=1}^V E_j^2}{V}$$

where V is number of data. Root mean square error can be expressed as:

$$RMSE = \sqrt{\frac{\sum_{j=1}^V E_j^2}{V}}$$

Table 3. Numerical analysis comparison of PID and PID-ILC responses

Joints	Control type	RMSE	MSE
Hip	PID	0.141532	0.020031
	PID-ILC	0.080999698	0.01
Knee	PID	0.162832	0.026514
	PID-ILC	0.09	0.01

4. CONCLUSION

A gait trainer with a lower limb exoskeleton has been created. As a result of the suggested hybrid PID-ILC controller, a robot-assisted gait trainer with unmodeled dynamics, uncertainty, and disturbance can track the gait trajectory. The actual experiment using load and particular controller gain showed that the system controlled using PID only has stability but with steady-state errors up to 10 degrees. The proposed using hybrid PID-ILC controller showed stability with its initial steady-state error. But after more than ten iterations, the steady-state error can be reduced to less than 1 degree. The steady-state errors are greatly reduced to 50%.

ACKNOWLEDGEMENTS

The writers would like to express their gratitude to the Sanata Dharma Foundation, Yogyakarta, Indonesia, for providing research funds and Rajamangala University of Technology Thanyaburi (RMUTT), Thailand, for providing research facilities.

REFERENCES

- [1] Y. R. Li, *Cardiovascular diseases: from molecular pharmacology to evidence-based therapeutics*. New Jersey: John Wiley & Sons, 2015.
- [2] E. J. Benjamin *et al.*, "Heart disease and stroke statistics—2017 Update: A report from the American heart association," *Circulation*, vol. 135, no. 10, Mar. 2017, doi: 10.1161/CIR.0000000000000485.
- [3] N. Venketasubramanian, B. W. Yoon, J. Pandian, and J. C. Navarro, "Stroke epidemiology in South, East, and South-East Asia: A review," *Journal of Stroke*, vol. 19, no. 3, pp. 286–294, Sep. 2017, doi: 10.5853/jos.2017.00234.
- [4] M. P. M. van Nunen, "Recovery of walking ability using a robotic device," *Amsterdam*, 2013. Accessed Jul. 06, 2021. [Online]. Available: https://research.vu.nl/files/42114296/complete_dissertation.pdf
- [5] K. H. Do and M. H. Chun, "Clinical use of robots as a part of rehabilitation medicine," *Brain & Neurorehabilitation*, vol. 10, no. 1, 2017, doi: 10.12786/bn.2017.10.e7.
- [6] A. Esquenazi, "Comment on 'assessing effectiveness and costs in robot-mediated lower limbs rehabilitation: A meta-analysis and State of the art,'" *Journal of Healthcare Engineering*, vol. 2018, pp. 1–3, Nov. 2018, doi: 10.1155/2018/7634965.
- [7] N. Radjou and J. Prabhu, *Frugal innovation: How to do better with less*. London: Profile Books, 2015.
- [8] V.-T. Tran and P. Ravaut, "Frugal innovation in medicine for low resource settings," *BMC Medicine*, vol. 14, no. 1, Dec. 2016, doi: 10.1186/s12916-016-0651-1.
- [9] Shihuh-Jer Huang and Ji-Shin Lee, "A stable self-organizing fuzzy controller for robotic motion control," *IEEE Transactions on Industrial Electronics*, vol. 47, no. 2, pp. 421–428, Apr. 2000, doi: 10.1109/41.836358.
- [10] Byung Kook Yoo and Woon Chul Ham, "Adaptive control of robot manipulator using fuzzy compensator," *IEEE Transactions on Fuzzy Systems*, vol. 8, no. 2, pp. 186–199, Apr. 2000, doi: 10.1109/91.842152.
- [11] D. A. Bristow, "A survey of iterative learning control," *IEEE Control Systems*, vol. 26, no. 3, pp. 96–114, Jun. 2006, doi: 10.1109/MCS.2006.1636313.
- [12] D. A. Bristow, K. L. Barton, and A. G. Alleyne, *Iterative learning control*, Control Sy. Ed. Boca Raton: CRC Press, 2011.
- [13] A. Madady, "PID type iterative learning control with optimal gains," *International Journal of Control, Automation, and Systems*, vol. 6, no. 2, pp. 194–203, 2008.
- [14] A. P. P. A. Majeed *et al.*, "The control of a lower limb exoskeleton for gait rehabilitation: A hybrid active fForce control approach," *Procedia Computer Science*, vol. 105, pp. 183–190, 2017, doi: 10.1016/j.procs.2017.01.204.
- [15] M. S. Amiri, R. Ramli, and M. F. Ibrahim, "Initialized model reference adaptive control for lower limb exoskeleton," *IEEE Access*, vol. 7, pp. 167210–167220, 2019, doi: 10.1109/ACCESS.2019.2954110.
- [16] M. R. Tucker *et al.*, "Control strategies for active lower extremity prosthetics and orthotics: a review," *Journal of NeuroEngineering and Rehabilitation*, vol. 12, no. 1, p. 1, 2015, doi: 10.1186/1743-0003-12-1.
- [17] D. Maneetham, *Industrial robotics & mechatronics applications*. Bangkok: SE-Education, 2018.
- [18] J. Hamill, K. M. Knutzen, and T. R. Derrick, *Biomechanical basis of human movement*, 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2015.
- [19] K. H. Low, "Robot-assisted gait rehabilitation: From exoskeletons to gait systems," in *2011 Defense Science Research Conference and Expo (DSR)*, Aug. 2011, pp. 1–10, doi: 10.1109/DSR.2011.6026886.
- [20] J. C. Moreno, F. Brunetti, E. Rocon, and J. L. Pons, "Immediate effects of a controllable knee ankle foot orthosis for functional compensation of gait in patients with proximal leg weakness," *Medical & Biological Engineering & Computing*, vol. 46, no. 1, pp. 43–53, Jan. 2008, doi: 10.1007/s11517-007-0267-x.
- [21] J. M. Hollerbach, I. W. Hunter, and J. Ballantyne, *A comparative analysis of actuator technologies for robotics*. Cambridge: The MIT Press, 1992.
- [22] J. G. Ziegler and N. B. Nichols, "Optimum settings for automatic controllers," *Journal of Dynamic Systems, Measurement, and Control*, vol. 115, no. 2B, pp. 220–222, Jun. 1993, doi: 10.1115/1.2899060.
- [23] K. H. Ang, G. Chong, and Yun Li, "PID control system analysis, design, and technology," *IEEE Transactions on Control Systems*

- Technology, vol. 13, no. 4, pp. 559–576, Jul. 2005, doi: 10.1109/TCST.2005.847331.
- [24] K. J. Åström, T. Hägglund, C. C. Hang, and W. K. Ho, “Automatic tuning and adaptation for PID controllers - a survey,” *Control Engineering Practice*, vol. 1, no. 4, pp. 699–714, Aug. 1993, doi: 10.1016/0967-0661(93)91394-C.
- [25] O. A. Somefun, K. Akingbade, and F. Dahunsi, “The dilemma of PID tuning,” *Annual Reviews in Control*, vol. 52, pp. 65–74, 2021, doi: 10.1016/j.arcontrol.2021.05.002.
- [26] P. Sutyasadi and M. Pamichkun, “Push recovery control of quadruped robot using particle swarm optimization based structure specified mixed sensitivity H_2/H_∞ control,” *Industrial Robot: the international journal of robotics research and application*, vol. 47, no. 3, pp. 423–434, Mar. 2020, doi: 10.1108/IR-06-2019-0135.
- [27] M. W. Hasan and N. H. Abbas, “An improved swarm intelligence algorithms-based nonlinear fractional order-PID controller for a trajectory tracking of underwater vehicles,” *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 18, no. 6, pp. 3173–3183, Dec. 2020, doi: 10.12928/telkomnika.v18i6.16282.
- [28] M. A. Faraj and A. Mohammed Abbood, “Fractional order PID controller tuned by bat algorithm for robot trajectory control,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 21, no. 1, pp. 74–83, Jan. 2021, doi: 10.11591/ijeecs.v21i1.pp74-83.
- [29] K. G. Abdulhussein, N. M. Yasin, and I. J. Hasan, “Comparison between butterfly optimization algorithm and particle swarm optimization for tuning cascade PID control system of PMDC motor,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 2, pp. 736–744, Jun. 2021, doi: 10.11591/ijpeds.v12.i2.pp736-744.
- [30] J. A. Shah and S. S. Rattan, “Dynamic analysis of two link robot manipulator for control design using PID computed torque control,” *IAES International Journal of Robotics and Automation (IJRA)*, vol. 5, no. 4, pp. 277–283, Dec. 2016, doi: 10.11591/ijra.v5i4.pp277-283.
- [31] A. Prayitno, V. Indrawati, and I. Trusulaw, “International conference on recent trends in physics 2016 (ICRTP2016),” *Journal of Physics: Conference Series*, vol. 755, Oct. 2016, doi: 10.1088/1742-6596/755/1/011001.
- [32] I. Erenoglu, I. Eksin, E. Yesil, and M. Guzelkaya, “An intelligent hybrid fuzzy Pid controller,” in *ECMS 2006 Proceedings edited by: W. Borutzky, A. Orsoni, R. Zobel*, May 2006, pp. 62–66, doi: 10.7148/2006-0062.
- [33] K. Abidi and J.-X. Xu, *Advanced discrete-time control*, vol. 23. Singapore: Springer Singapore, 2015.
- [34] D. Somwanshi, M. Bundele, G. Kumar, and G. Parashar, “Comparison of fuzzy-PID and PID controller for speed control of DC motor using LabVIEW,” *Procedia Computer Science*, vol. 152, pp. 252–260, 2019, doi: 10.1016/j.procs.2019.05.019.
- [35] N. H. Abdul Razak Ramesh, M. R. Ghazali, and M. A. Ahmad, “Sigmoid PID based adaptive safe experimentation dynamics algorithm of portable duodopa pump for Parkinson’s disease patients,” *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 2, pp. 632–639, Apr. 2021, doi: 10.11591/eei.v10i2.2542.
- [36] R. G. Sanfelice, *Hybrid feedback control*. Princeton: Princeton University Press, 2021.
- [37] S. Arimoto, S. Kawamura, and F. Miyazaki, “Bettering operation of robots by learning,” *Journal of Robotic Systems*, vol. 1, no. 2, pp. 123–140, 1984, doi: 10.1002/rob.4620010203.
- [38] D. H. Owens and J. Hätönen, “Iterative learning control — An optimization paradigm,” *Annual Reviews in Control*, vol. 29, no. 1, pp. 57–70, Jan. 2005, doi: 10.1016/j.arcontrol.2005.01.003.
- [39] F.-M. Chen *et al.*, “An improvement on the transient response of tracking for the sampled-data system based on an improved PD-type iterative learning control,” *Journal of the Franklin Institute*, vol. 351, no. 2, pp. 1130–1150, Feb. 2014, doi: 10.1016/j.jfranklin.2013.10.014.
- [40] X. Li, Q. Ren, and J. Xu, “Precise speed tracking control of a robotic fish via iterative learning control,” *IEEE Transactions on Industrial Electronics*, vol. 63, no. 4, pp. 1–1, 2015, doi: 10.1109/TIE.2015.2499719.
- [41] K. L. Moore, *Iterative learning control for deterministic systems*. London: Springer London, 1993.
- [42] P. Sutyasadi and M. Pamichun, “Trotting control of a quadruped robot using PID-ILC,” in *IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society*, Nov. 2015, pp. 4400–4405, doi: 10.1109/IECON.2015.7392784.
- [43] D. Maneetham and P. Sutyasadi, “Controlling a knee CPM machine using PID and iterative learning control algorithm,” *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 18, no. 2, pp. 1047–1053, Apr. 2020, doi: 10.12928/telkomnika.v18i2.14876.
- [44] M. Rezaei Estakhrouieh and A. Gharaveisi, “Optimal iterative learning control design for generator voltage regulation system,” *Turkish Journal of Electrical Engineering and Computer Sciences*, vol. 21, pp. 1909–1919, 2013, doi: 10.3906/elk-1203-19.
- [45] G. Bovi, M. Rabuffetti, P. Mazzoleni, and M. Ferrarin, “A multiple-task gait analysis approach: Kinematic, kinetic and EMG reference data for healthy young and adult subjects,” *Gait & Posture*, vol. 33, no. 1, pp. 6–13, Jan. 2011, doi: 10.1016/j.gaitpost.2010.08.009.
- [46] P. O. J. Kaltjob, *Control of mechatronic systems: model-driven design and implementation guidelines*. West Sussex: John Wiley & Sons, 2021.
- [47] N. J. Salkind, B. B. Frey, D. M. Dougherty, K. R. Teasdale, and N. Hill-Kapturczak, *Encyclopedia of research design*. Thousand Oaks, California: SAGE Publications, 2010.

BIOGRAPHIES OF AUTHORS



Elang Parikesit    received his bachelor's degree in electrical engineering from Diponegoro University, Indonesia in 1997 and a master's degree in biomedical engineering from Institut Teknologi Bandung (ITB) in 2012. He is a lecturer at the Electromedical Technology Department of Sanata Dharma University, Yogyakarta, Indonesia. He went to Rajamangala University of Technology Thanyaburi, Thailand to continue his doctoral degree in mechatronics engineering. His research interest includes renewable energy, mechatronics, and biomedical engineering. He can be contacted at email: elang_p@mail.rmutt.ac.th or elang@usd.ac.id.



Dechrit Maneetham    is an Associate Professor of Mechatronics Engineering at Rajamangala University of Technology Thanyaburi, Thailand. He received his B.Tech. and M.S. degrees from King Mongkut's University of Technology, North Bangkok and his D.Eng. in Mechatronics degree from the Asian Institute of Technology in 2010, and his Ph.D. in Electrical and Computer Engineering from Mahasarakham University in 2018. His research interest includes biomedical applications, robotics and automation applications, and mechatronics applications. He can be contacted at email: dechrit_m@rmutt.ac.th.



Petrus Sutyasadi    obtained a master's degree in mechatronics in 2008 and a doctorate in mechatronics in 2016 from the Asian Institute of Technology in Thailand. Currently, He is a lecturer at the Department of Mechatronics Engineering, Sanata Dharma University, Yogyakarta, Indonesia. His research interests include robust control, robotics, and frugal innovation in mechatronic engineering. He can be contacted at email: peter@usd.ac.id.