Brought to you by IPB University

Source details

International Journal for Simulation and Multidisciplinary Design Optimization

Open Access

Scopus coverage years: from 2017 to Present
Publisher: EDP Sciences
E-ISSN: 1779-6288
Subject area: Mathematics: Control and Optimization   Mathematics: Modeling and Simulation
Source type: Journal

CiteScore 2020
0.9

SJR 2020
0.193

SNIP 2020
0.733

View all documents >   Set document alert   Save to source list   Source Homepage

CiteScore   CiteScore rank & trend   Scopus content coverage

i Improved CiteScore methodology

CiteScore 2020 counts the citations received in 2017-2020 to articles, reviews, conference papers, book chapters and data papers published in 2017-2020, and divides this by the number of publications published in 2017-2020. Learn more >

CiteScore 2020

0.9 = 54 Citations 2017 - 2020 / 58 Documents 2017 - 2020

Calculated on 05 May, 2021

CiteScoreTracker 2021

1.1 = 81 Citations to date / 77 Documents to date

Last updated on 06 April, 2022 • Updated monthly

CiteScore rank 2020

Category	Rank	Percentile
Mathematics — Control and Optimization	#87/111	22nd
Mathematics — Modeling and Simulation	#248/290	14th

View CiteScore methodology >   CiteScore FAQ >   Add CiteScore to your site

Brought to you by IPB University

International Journal for Simulation and Multidisciplinary Design Optimization • *Open Access* • Volume 11 • 2020 • Article number 12

Document type
Article • *Gold Open Access* • *Green Open Access*

Source type
Journal

ISSN
17796288

DOI
10.1051/smdo/2020007

View more

System design for inverted pendulum using LQR control via IoT

Maneetham, Dechrit[a] ; Sutyasadi, Petrus[b]
Save all to author list

[a] Department of Mechatronics Engineering, Rajamagala University of Technology Thanyaburi, Thailand
[b] Department of Mechatronics Engineering, Mechatronics Polytechnic of Sanata Dharma, Yogyakarta, Indonesia

1 41th percentile Citation in Scopus | 0.22 FWCI | 5 Views count | View all metrics >

View PDF Full text options Export

Abstract
This research proposes control method to balance and stabilize an inverted pendulum. A robust control was analyzed and adjusted to the model output with real time feedback. The feedback was obtained using state space equation of the feedback controller. A linear quadratic regulator (LQR) model tuning and control was applied to the inverted pendulum using internet of things (IoT). The system's conditions and performance could be monitored and controlled via personal computer (PC) and mobile phone. Finally, the inverted pendulum was able to be controlled using the LQR controller and the IoT communication developed will monitor to check the all conditions and performance results as well as help the inverted pendulum improved various operations of IoT control is discussed. © D. Maneetham and P. Sutyasadi, published by EDP Sciences, 2020.

Author keywords
Inverted pendulum; IoT; LQR control; Simulink; State space control

Cited by 1 document

The Problem of Balancing an Inverted Spherical Pendulum on an Omniwheel Platform
Shaura, A.S. , Tenenev, V.A. , Vetchanin, E.V.
(2021) Russian Journal of Nonlinear Dynamics

View details of this citation

Inform me when this document is cited in Scopus:

Set citation alert >

Related documents

Performance analysis of packet loss on wireless network control systems
Quang, N.V.A. , Yoo, M.
(2014) International Conference on ICT Convergence

Swing up and Stabilization of Rotational Inverted Pendulum by Fuzzy Sliding Mode Controller
Rajeswari, K. , Vivek, P. , Nandhagopal, J.
(2020) Lecture Notes on Data Engineering and Communications Technologies

An exact differential flatness control for a non minimum phase model of an inverted pendulum
Mansour, A. , Jerbi, H.
(2009) Proceedings - 2009 3rd Asia International Conference on Modelling and Simulation, AMS 2009

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

Abstract

Author keywords

Indexed keywords

Sustainable Development Goals 2021

SciVal Topics

Metrics

1 Udhayakumar, K., Lakshmi, P.
Design of robust energy control for cart inverted pendulum
(2007) *Int. J. Eng. Technol.*, 4, pp. 66-76. Cited 12 times.

2 Bradshaw, A., Shao, J.
Swing-up control of inverted pendulum systems (Open Access)
(1996) *Robotica*, 14 (4), pp. 397-405. Cited 37 times.
http://uk.cambridge.org/journals/journal_catalogue.asp?historylinks=ALPHA&mnemonic=ROB
doi: 10.1017/s0263574700019792
View at Publisher

3 Yi, J., Yubazaki, N., Hirota, K.
A new fuzzy controller for stabilization of parallel-type double inverted pendulum system
(2002) *Fuzzy Sets and Systems*, 126 (1), pp. 105-119. Cited 98 times.
doi: 10.1016/S0165-0114(01)00028-8
View at Publisher

4 Chen, Y.-P., Chang, J.-L., Chu, S.-R.
PC-based sliding-mode control applied to parallel-type double inverted pendulum system
(1999) *Mechatronics*, 9 (5), pp. 553-564. Cited 25 times.
doi: 10.1016/S0957-4158(99)00015-X
View at Publisher

5 Li, Z., Zhang, X., Chen, C., Guo, Y.
The modeling and simulation on sliding mode control applied in the double inverted pendulum system
(2012) *Proceedings of the World Congress on Intelligent Control and Automation (WCICA)*, art. no. 6358042, pp. 1089-1091. Cited 4 times.
ISBN: 978-146731398-8
doi: 10.1109/WCICA.2012.6358042
View at Publisher

6 Bian, Y., Jiang, J., Xu, X., Zhu, L.
Research on inverted pendulum network control technology
(2011) *Proceedings - 3rd International Conference on Measuring Technology and Mechatronics Automation, ICMTMA 2011*, 3, art. no. 5721411, pp. 11-13. Cited 5 times.
ISBN: 978-076954296-6
doi: 10.1109/ICMTMA.2011.574
View at Publisher

7 Yu, L.H., Jian, F.
An inverted pendulum fuzzy controller design and simulation
(2014) *Proceedings - 2014 International Symposium on Computer, Consumer and Control, IS3C 2014*, art. no. 6845943, pp. 557-559. Cited 12 times.
ISBN: 978-147995277-9
doi: 10.1109/IS3C.2014.151
View at Publisher

Abstract

Author keywords

Indexed keywords

Sustainable Development Goals 2021

SciVal Topics

Metrics

☐ 8 Lim, Y.Y., Hoo, C.L., Felicia Wong, Y.M.
Stabilising an Inverted Pendulum with PID Controller (Open Access)

(2018) *MATEC Web of Conferences*, 152, art. no. 02009. Cited 9 times.
http://www.matec-conferences.org/
doi: 10.1051/matecconf/201815202009

View at Publisher

☐ 9 Xin, Y., Xu, J., Xu, B., Xin, H.
The inverted-pendulum model with consideration of pendulum resistance and its LQR controller

(2011) *Proceedings of 2011 International Conference on Electronic and Mechanical Engineering and Information Technology, EMEIT 2011*, 7, art. no. 6023822, pp. 3438-3441. Cited 7 times.
ISBN: 978-161284085-7
doi: 10.1109/EMEIT.2011.6023822

View at Publisher

☐ 10 Ramashis, B., Naiwritadey, U.
Stabilization of double link inverted pendulum using LQR
(2018) *Ieee Int. Conf. Curr. Trends Toward Conver. Technolog. India*, pp. 1-6.

© Copyright 2020 Elsevier B.V., All rights reserved.

About Scopus

What is Scopus
Content coverage
Scopus blog
Scopus API
Privacy matters

Language

日本語に切り替える
切换到简体中文
切換到繁體中文
Русский язык

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.

RELX

International Journal for Simulation and Multidisciplinary Design Optimization

COUNTRY

France

Universities and research institutions in France

SUBJECT AREA AND CATEGORY

Mathematics
- Control and Optimization
- Modeling and Simulation

PUBLISHER

EDP Sciences

H-INDEX

6

PUBLICATION TYPE

Journals

ISSN

17796288

COVERAGE

2017-2021

INFORMATION

Homepage

How to publish in this journal

SCOPE

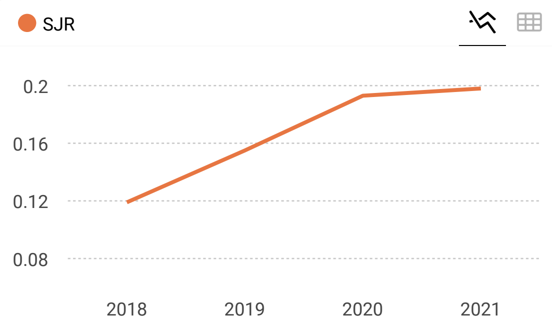
The International Journal for Simulation and Multidisciplinary Design Optimization is a peer-reviewed journal covering all aspects related to the simulation and multidisciplinary design optimization. It is devoted to publish original work related to advanced design methodologies, theoretical approaches, contemporary computers and their applications to different fields such as engineering software/hardware developments, science, computing techniques, aerospace, automobile, aeronautic, business, management, manufacturing,... etc. Front-edge research topics related to topology optimization, composite material design, numerical simulation of manufacturing process, advanced optimization algorithms, industrial applications of optimization methods are highly suggested. The scope includes, but is not limited to original research contributions, reviews in the following topics: Parameter identification & Surface Response (all aspects of characterization and modeling of materials and structural behaviors, Artificial Neural Network, Parametric Programming, approximation methods,…etc.) Optimization Strategies (optimization methods that involve heuristic or Mathematics approaches, Control Theory, Linear & Nonlinear Programming, Stochastic Programming, Discrete & Dynamic Programming, Operational Research, Algorithms in Optimization based on nature behaviors,….etc.) Structural Optimization (sizing, shape and topology optimizations with or without external constraints for materials and structures) Dynamic and Vibration (cover modelling and simulation for dynamic and vibration analysis, shape and topology optimizations with or without external constraints for materials and structures) Industrial Applications (Applications Related to Optimization, Modelling for Engineering applications are very welcome. Authors should underline the technological, numerical or integration of the mentioned scopes.).

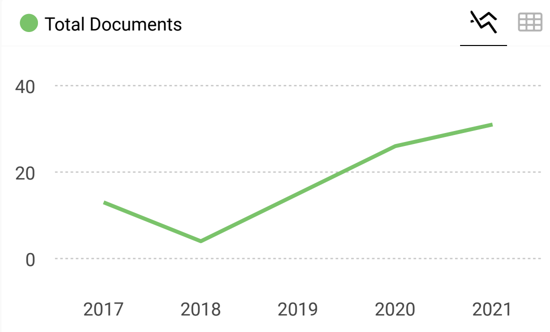
Join the conversation about this journal

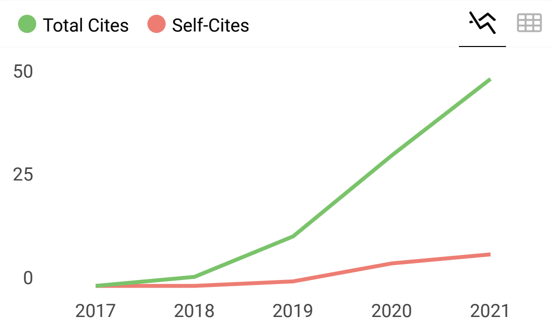
Quartiles

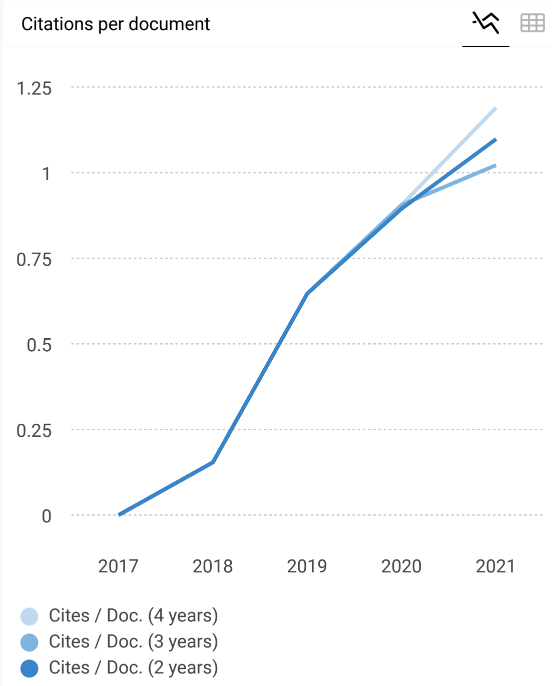
FIND SIMILAR JOURNALS

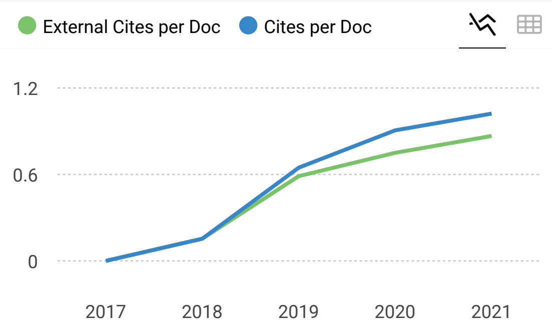
Loading journals…

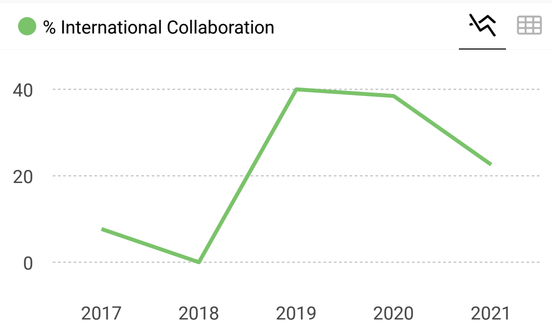


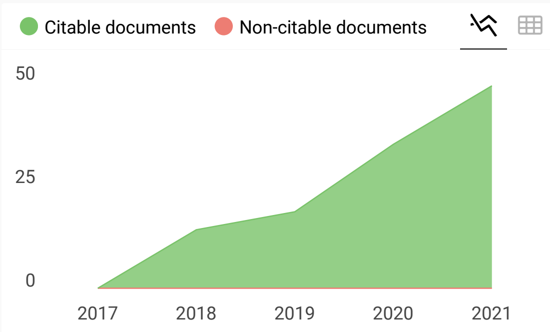


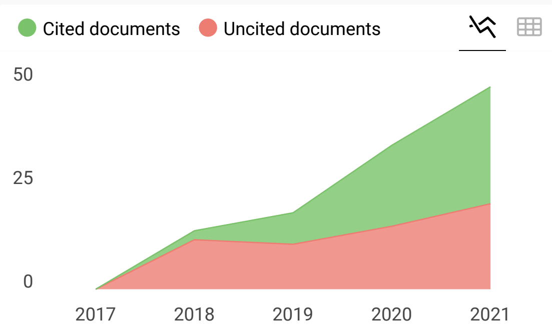












← Show this widget in your own website

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

<a href="https://www.scima

SCImago Graphica

Explore, visually communicate and make sense of data with our **new free tool**.

By using this website, you agree that EDP Sciences may store web audience measurement cookies and, on some pages, cookies from social networks. More information and setup

OK

Vol. 13 (2022)

By using this website, you agree that EDP Sciences may store web audience measurement cookies and, on some pages, cookies from social networks. More information and setup OK

The *International Journal for Simulation and Multidisciplinary Design Optimization* is a peer-reviewed journal covering all aspects related to the simulation and multidisciplinary design optimization. Read more

Latest articles   Most read articles

Open Access
Minimizing the variance of the coverage ratio as an approach to optimize the exchange rate risk of Brent futures contracts
Mustapha Bouchekourte, Sara Rhouas and Norelislam El Hami
Published online: 19 May 2022

Advances in Modeling and Optimization of Manufacturing Processes
Open Access
Selection of raw material supplier for cold-rolled mild steel manufacturing industry
Avinash G. Kamble, Pritam S. Kalos, K. Mahapatra and Vishal A. Bhosale
Published online: 15 March 2022

Open Access
Design and analysis of shell and tube heat exchanger
Erica Jacqueline Fernandes and Sachidananda Hassan Krishanmurthy
Published online: 28 February 2022

Open Access
Analysis of microchannel heat exchanger based on channel geometry
Mohammed Faris Tahasildar and Sachidananda Hassan Krishanmurthy
Published online: 28 February 2022

Computation Challenges for engineering problems
Open Access
Prediction and optimization of performance and emission characteristics of a dual fuel engine using machine learning
Krishnasamy Karunamurthy, Mohammed Musthafa Feroskhan, Ganesan Suganya and Ismail Saleel
Published online: 22 February 2022

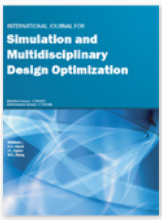
Simulation and Optimization for Industry 4.0
Open Access
Optimization of equity allocations of institutional investors: study of Moroccan case
Mustapha Bouchekourte and Norelislam El Hami
Published online: 08 February 2022

Submit your paper

Instruction for authors

Sign up for Email-alert

Recommend this journal



Editors-in-Chief: David H. Bassir and Zhang Weihong

eISSN: 1779-6288

Open access journal

By using this website, you agree that EDP Sciences may store web audience measurement cookies and, on some pages, cookies from social networks. More information and setup

OK

Published in partnership with

Northwestern Polytechnical University (NPU), China

The Association for Simulation and Multidisciplinary Design Optimization (ASMDO)

News

DOAJ Seal awarded to International Journal for Simulation and Multidisciplinary Design Optimization demonstrating “best practice in open access publishing”

Call for Papers for a Special Issue on "Advances in Modeling and Optimization of Manufacturing Processes"

More News

International Journal for Simulation and Multidisciplinary Design Optimization (IJSMDO)

Editors-in-Chief: David H. Bassir and Zhang Weihong - Editorial board

eISSN : 1779-6288

By using this website, you agree that EDP Sciences may store web audience measurement cookies and, on some pages, cookies from social networks. More information and setup OK

Editorial board

Editors-in-chief

David H. Bassir
Université de Technologie de Belfort-Montbéliard, Belfort, France
Institute of Industry Technology, Guangzhou & Chinese Academy of Sciences (IIT, GZ&CAS), Haibin Rd, Nansha District, Guangzhou, China

Weihong Zhang
Member of the Chinese Academy of Sciences
Northwestern Polytechnical University, Sino-French Laboratory of Concurrent Engineering, Institute of Mechatronic Engineering, China

Associate Editors

Zhu Ji-hong, Northwestern Polytechnical University, China

Sofiane Guessasma, French National Institute for Agricultural Research, Nantes, France

A. El Hami, INSA de Rouen Normandie, Normandy University, France

Journal Advisor

Jose Luis Zapico Valle, University of Oviedo, Campus de Gijón, Spain

Advisory Board Members

P. Baiocco, CNES / ESA, France
K. Barkaoui, Conservatoire National des Arts et Métiers (CNAM), Paris, France
A.W. Blom, TUDelft / Stork Fokker AESP, The Netherlands
W. Chen, Northwestern University, IL, USA
E.S. de Cursi, INSA-Rouen, France
T.R. Chandrupatla, Rowan University, NJ, USA
Jiang Chao, College of Mechanical and Vehicle Engineering, Hunan University, Changsha City, China
E.J. Cramer, Boeing, USA
K. Deb, Indian Institute of Technology Kanpur, India
R. Dornberger, UAS Solothurn Northwestern Switzerland
M. El Ganaoui, Université de Lorraine, IUT Henri Poincaré de Longwy, France
M.I. Friswell, University of Bristol, UK
H.C. Gea, The Statae university of New Jersey, USA

By using this website, you agree that EDP Sciences may store web audience measurement cookies and, on some pages, cookies from social networks. More information and setup

OK

Z. Gürdal, Delft University of Technology, The Netherlands
S. Hernández, University of a Coruña, Spain
A. El Hami, INSA-Rouen, France
S.T. Liu, Dalian University of Technology, China
J. Majak, Tallin University of technology, Estonia
P.M. Montrull, Polytechnic University of Cartagena, Spain
C.A. Mota Soares, IDMEC / IST, Technical University of Lisbon, Portugal
Z. Moumni, ENSTA Paristech, France
J.P. Pedroso, Faculdade de Ciencias da Univ. do Porto, Portugal
C. Poloni, University of Trieste, Italy
M. Klein, INTES GmbH, Stuttgart, Germany
S.D. Rajan, Arizona State University, USA
H. Rodrigues, Technical University of Lisboa, Portugal
V. Sahadevan, Atkins Aviation & Defence Systems, UK
O. Sigmund, Technical University of Denmark, Denmark
S. Taher, University of Blida, Algeria
E.G. Talbi, University of Sciences and Technologies of Lille, France
O. de Weck, MIT, USA
G. Winter, CEANI / Univ. of Las Palmas de Gran Canaria, Spain
Bo Wang, Department of Engineering Mechanics, Dalian University of Technology, China
Qi Xia, Institute and Address: Huazhong University of Science and Technology, Wuhan, China
K. Yamazaki, Kanazawa University, Japan
Jun Yan, State Key Lab. of Structural Analysis for Industrial Equip. Dept. of Engineering Mechanics, Dalian University of Technology, China
J. Zarka, CADLM, France
M. Zhou, Altair Engineering, USA

International Journal for Simulation and Multidisciplinary Design Optimization (IJSMDO)
Editors-in-Chief: David H. Bassir and Zhang Weihong - Editorial board
eISSN : 1779-6288

By using this website, you agree that EDP Sciences may store web audience measurement cookies and, on some pages, cookies from social networks. More information and setup

OK

Free Access to the whole issue

International Journal for Simulation and Multidisciplinary Design Optimization

Volume 11 (2020)

Export the citation of the selected articles Export

Select all

By using this website, you agree that EDP Sciences may store web audience measurement cookies and, on some pages, cookies from social networks. More information and setup

OK

Published online: 25 September 2020

DOI: https://doi.org/10.1051/smdo/2020015

Full HTML | PDF (908.4 KB) | ePUB (2.752 MB) | References

Open Access

A numerical model of elasticity for cardiovascular system that includes 2/3D displacements and deformations 20

Ayoub Azzayani

Published online: 11 September 2020

DOI: https://doi.org/10.1051/smdo/2020014

Full HTML | PDF (3.287 MB) | ePUB (7.009 MB) | References

Open Access

Flexible rotor optimization design with considering the uncertainty of unbalance distribution 19

Shengxi Jia, Longxi Zheng and Qing Mei

Published online: 13 August 2020

DOI: https://doi.org/10.1051/smdo/2020005

Full HTML | PDF (1.219 MB) | ePUB (1.934 MB) | References

Open Access

Factorial design and design of experiments for developing novel lead free solder alloy with Sn, Cu and Ni 18

Jayesh S, Jacob Elias and Manoj Guru

Published online: 10 August 2020

DOI: https://doi.org/10.1051/smdo/2020013

Full HTML | PDF (636.0 KB) | ePUB (1.331 MB) | References

Open Access

Optimality and duality for nonsmooth semi-infinite E-convex multi-objective programming with support functions 17

Tarek Emam

Published online: 10 August 2020

DOI: https://doi.org/10.1051/smdo/2020011

Full HTML | PDF (256.5 KB) | ePUB (975.8 KB) | References

Open Access

Modified election algorithm in hopfield neural network for optimal random *k* satisfiability representation 16

Hamza Abubakar, Shamsul Rijal Muhammad Sabri, Sagir Abdu Masanawa and Surajo Yusuf

Published online: 07 August 2020

DOI: https://doi.org/10.1051/smdo/2020008

Full HTML | PDF (1.113 MB) | ePUB (1.872 MB) | References

Open Access

Preliminary investigations on extrusion of high viscosity slurry using direct writing technique 15

Ali Tesfaye Kebede, Esakki Balasubramanian, AS Praveen, Lade Rohit and Kumar Arvind

Published online: 06 August 2020

DOI: https://doi.org/10.1051/smdo/2020012

Full HTML | PDF (4.117 MB) | ePUB (3.152 MB) | References

Open Access

Modeling of a square-shape ZnO, ZnS and AlN membrane for mems capacitive pressure-sensor applications 14

Ahmad Dagamseh, Qais Al-Bataineh, Zaid Al-Bataineh, Nermeen S. Daoud, Ahmad Alsaad and Ahmad Omari

Published online: 04 August 2020

DOI: https://doi.org/10.1051/smdo/2020010

Full HTML | PDF (1.773 MB) | ePUB (3.527 MB) | References

Open Access

Agent-based modelling and simulation for ship unloading processes: determining the number of trucks and container cranes 13

Fadillah Ramadhan, Arif Imran, Afrin Fauzya Rizana and Liane Okdinawati

Published online: 04 August 2020

DOI: https://doi.org/10.1051/smdo/2020009

Full HTML | PDF (967.9 KB) | ePUB (2.013 MB) | References

By using this website, you agree that EDP Sciences may store web audience measurement cookies and, on some pages, cookies from social networks. More information and setup

OK

System design for inverted pendulum using LQR control via IoT 12
Dechrit Maneetham and Petrus Sutyasadi
Published online: 28 July 2020
DOI: https://doi.org/10.1051/smdo/2020007
Full HTML | PDF (1.230 MB) | ePUB (2.387 MB) | References

Open Access
Multiobjective aerodynamic shape optimization of NACA0012 airfoil based mesh morphing 11
Rabii El Maani, Soufiane Elouardi, Bouchaib Radi and Abdelkhalak El Hami
Published online: 24 July 2020
DOI: https://doi.org/10.1051/smdo/2020006
Full HTML | PDF (3.143 MB) | ePUB (3.461 MB) | References

Open Access
A tabu search approach with embedded nurse preferences for solving nurse rostering problem 10
Razamin Ramli, Siti Nurin Ima Ahmad, Syariza Abdul-Rahman and Antoni Wibowo
Published online: 24 July 2020
DOI: https://doi.org/10.1051/smdo/2020002
Full HTML | PDF (1.463 MB) | ePUB (2.326 MB) | References

Open Access
Cleaning cycle optimisation in non-tracking ground mounted solar PV systems using Particle Swarm Optimisation 9
K. Chiteka, R. Arora, S.N. Sridhara and C.C. Enweremadu
Published online: 14 July 2020
DOI: https://doi.org/10.1051/smdo/2020004
Full HTML | PDF (816.6 KB) | ePUB (2.182 MB) | References

Open Access
Influence of geometric variables on spur gear volume 8
Edmund S. Maputi and Rajesh Arora
Published online: 23 June 2020
DOI: https://doi.org/10.1051/smdo/2020003
Full HTML | PDF (2.000 MB) | ePUB (4.544 MB) | References

Open Access
Frequency and temperature control for complex system engineering in optoelectronics and electronics: an overview 7
Patrice Salzenstein
Published online: 09 June 2020
DOI: https://doi.org/10.1051/smdo/2020001
Full HTML | PDF (487.7 KB) | ePUB (1.136 MB) | References

Open Access
CFD simulation for evaluation of optimum heat transfer rate in a heat exchanger of an internal combustion engine 6
Rajesh Kocheril and Jacob Elias
Published online: 28 February 2020
DOI: https://doi.org/10.1051/smdo/2019017
Full HTML | PDF (5.249 MB) | ePUB (4.862 MB) | References

Open Access
REVIEW
A comparative study of three new parallel models based on the PSO algorithm 5
Maria Zemzami, Norelislam El Hami, Mhamed Itmi and Nabil Hmina
Published online: 31 January 2020
DOI: https://doi.org/10.1051/smdo/2019022
Full HTML | PDF (2.753 MB) | ePUB (2.733 MB) | References

Open Access
Topology optimization of steering knuckle structure 4
Saurabh Srivastava, Sachin Salunkhe, Sarang Pande and Bhavin Kapadiya

By using this website, you agree that EDP Sciences may store web audience measurement cookies and, on some pages, cookies from social networks. More information and setup OK

Full HTML | PDF (6.011 MB) | ePUB (4.746 MB) | References

Open Access

A multi-discretization scheme for topology optimization based on the parameterized level set method 3

Peng Wei, Yang Liu and Zuyu Li

Published online: 24 January 2020

DOI: https://doi.org/10.1051/smdo/2019019

Full HTML | PDF (2.644 MB) | ePUB (2.684 MB) | References

Open Access

Optimization in collaborative information systems for an enhanced interoperability network 2

Aicha Koulou, Maria Zemzami, Norelislam El Hami, Abir Elmir and Nabil Hmina

Published online: 15 January 2020

DOI: https://doi.org/10.1051/smdo/2019021

Full HTML | PDF (1.029 MB) | ePUB (1.837 MB) | References

Open Access

Posture prediction and optimization for a manual assembly operation involving lifting of weights 1

Biswaranjan Rout, Rati Ranjan Dash and Debabrata Dhupal

Published online: 15 January 2020

DOI: https://doi.org/10.1051/smdo/2019020

Full HTML | PDF (1.884 MB) | ePUB (2.310 MB) | References

International Journal for Simulation and Multidisciplinary Design Optimization (IJSMDO)

Editors-in-Chief: David H. Bassir and Zhang Weihong - Editorial board

eISSN : 1779-6288

Int. J. Simul. Multidisci. Des. Optim. **11**, 12 (2020)
© D. Maneetham and P. Sutyasadi, published by EDP Sciences, 2020
https://doi.org/10.1051/smdo/2020007

IJSMDO

Available online at:
https://www.ijsmdo.org

RESEARCH ARTICLE

OPEN ACCESS

System design for inverted pendulum using LQR control via IoT

Dechrit Maneetham[1,*] and Petrus Sutyasadi[2]

[1] Department of Mechatronics Engineering, Rajamagala University of Technology Thanyaburi, Thailand
[2] Department of Mechatronics Engineering, Mechatronics Polytechnic of Sanata Dharma, Yogyakarta, Indonesia

Received: 15 October 2019 / Accepted: 27 March 2020

Abstract. This research proposes control method to balance and stabilize an inverted pendulum. A robust control was analyzed and adjusted to the model output with real time feedback. The feedback was obtained using state space equation of the feedback controller. A linear quadratic regulator (LQR) model tuning and control was applied to the inverted pendulum using internet of things (IoT). The system's conditions and performance could be monitored and controlled via personal computer (PC) and mobile phone. Finally, the inverted pendulum was able to be controlled using the LQR controller and the IoT communication developed will monitor to check the all conditions and performance results as well as help the inverted pendulum improved various operations of IoT control is discussed.

Keywords: Inverted pendulum / state space control / Simulink / LQR control / IoT

1 Introduction

Rotational and on-cart inverted pendulum are good example of non linear, unstable and high order systems that need to be stabilized. This balancing system is applied on high precision control such as on Segway, humanoid or some legged robots and so forth [1]. There are many kinds of theoretical control that can be applied to the inverted pendulum such as root locus, PID, Fuzzy logic, sliding mode or such new algorithms to balance and stabilize the inverted pendulum [2]. During balancing, the inertia forces from the mechanisms results a very large shaking force [3]. Dynamic balance can be achieved by adding mass to the system so that the inertia forces resulting from the added mass will be equal and opposite to those causing the shaking moment. Single inverted pendulum is an interesting nonlinear system to investigate [4]. Inverted pendulum is one of the most important plants in the science and industrial technologies [5] and ideal experiment device to test new control algorithm [6]. It because this system is poorly stable and has such as large of overshoot problem [7] and has a unique trait such as unpredictable, non-linear and consists of multiple variables [8]. Used in many studies The Linear Quadratic Regulator was applied to the inverted pendulum system that analyze performance of two different outputs between control cart position and pendulum angle [9,10]. Results of the experiment and simulation show that the LQR controller was able to compensate disturbances in the system and balance the inverted pendulum following the reference angle and cart position. Figure 1 shows the model of two type of inverted pendulum.

2 Research method

An inverted pendulum can be balanced either statically or dynamically. Static balance is accomplished by adding or removing weights until the component will remain stable. Dynamic balance is done by dynamically control the force to balance the system. Figure 2 shows the drawing and sum of forces applied on the system. All parameters involved are shown in Table 1.

Considering the inverted pendulum link in Figure 2, if the direction of the acceleration change then the direction of the associated inertia force is also constantly changing. It would be most convenient if the mass of the connecting rod could be replaced by one or more masses located where the direction of acceleration is more easily determined.

The mathematics model for cart

$$\rightarrow + \sum \vec{F} = m\vec{a} \tag{1}$$

$$F - H - c\dot{x} = m_c\ddot{x}$$

* e-mail: dechrit_m@rmutt.ac.th

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

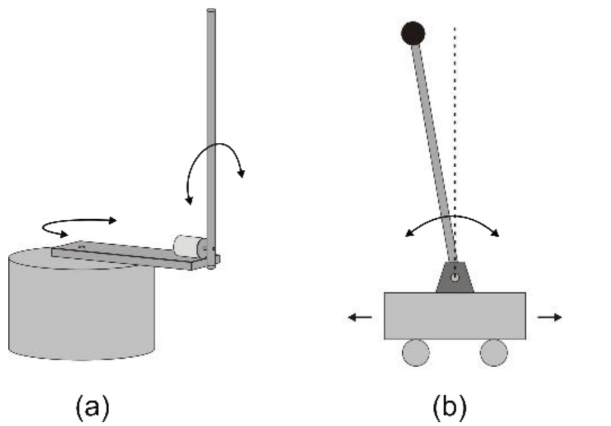


Fig. 1. (a) Rotary inverted pendulum. (b) On cart inverted pendulum.

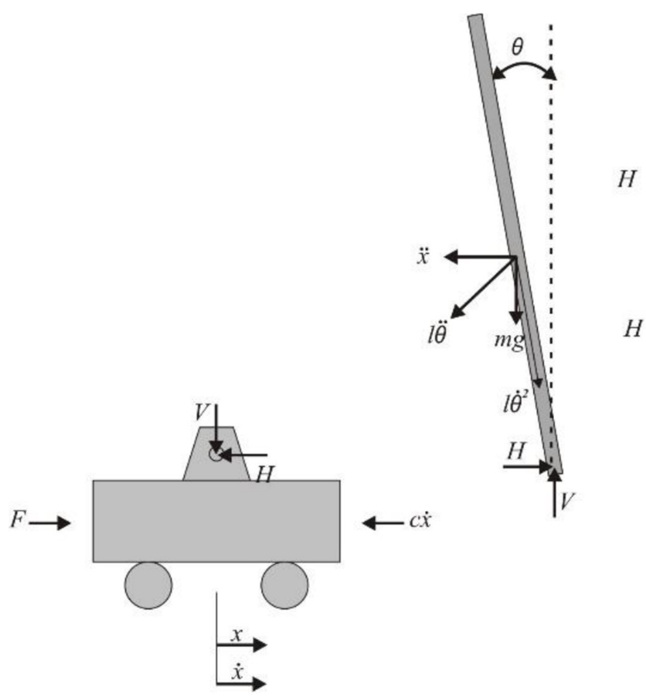


Fig. 2. Mechanical model of inverted pendulum.

The mathematics model for rod

$$\rightarrow + \sum \vec{F} = m\vec{a} \qquad (2)$$
$$H = m\left(\ddot{x} + l\ddot{\theta}\cos\theta - l\dot{\theta}^2\sin\theta\right)$$
$$H = m\ddot{x} + ml\ddot{\theta}\cos\theta - ml\dot{\theta}^2\sin\theta$$

$$\uparrow + \sum \vec{F} = 0 \qquad (3)$$
$$mlg\sin\theta - ml\ddot{x}\cos\theta - ml^2\ddot{\theta} - b\dot{\theta} = I\ddot{\theta}$$
$$V - mg = m\left(-l\ddot{\theta}\sin\theta - l\dot{\theta}^2\cos\theta\right)$$
$$V = mg - ml\ddot{\theta}\sin\theta - ml\dot{\theta}^2\cos\theta$$

$$CW + \sum \vec{\tau} = I\vec{\alpha} \qquad (4)$$
$$Vl\sin\theta - Hl\cos\theta - b\dot{\theta} - I\ddot{\theta}$$

Substitute equation (2) into equation (1) results in

$$F - m\ddot{x} - ml\ddot{\theta}\cos\theta + ml\dot{\theta}^2\sin\theta - c\dot{x} = m_c\ddot{x}$$
$$\ddot{x} = \frac{1}{(m_c + m)}\left[-ml\ddot{\theta}\cos\theta + ml\dot{\theta}^2\sin\theta - c\dot{x} + F\right]. \qquad (5)$$

Substitute equations (2), (3) into equation (4) results in

$$mlg\sin\theta - ml\ddot{x}\cos\theta - ml^2\ddot{\theta} - b\dot{\theta} = I\ddot{\theta}$$
$$\ddot{\theta} = \frac{1}{I + ml^2}\left[mlg\sin\theta - ml\ddot{x}\cos\theta - b\dot{\theta}\right]. \qquad (6)$$

The velocity and acceleration of the link are defined as $\theta \approx 0$, $\dot{\theta}^2\theta \approx 0$ and $\cos\theta \approx 1$. The period of the nonlinear model can substitute equations (5) and (6) will be calculated.

$$\ddot{x} = \frac{1}{(m_c + m)}\left[-ml\ddot{\theta} - c\dot{x} + F\right] \qquad (7)$$

$$\ddot{\theta} = \frac{1}{J}\left[mlg\theta - ml\ddot{x} - b\dot{\theta}\right] \qquad (8)$$

where $J = I + ml^2$.

Table 1. Parameter of inverted pendulum system.

Parameter	Symbol	Parameter	Symbol
Pendulum rod mass	m	Armature Resistance	R
Cart mass	m_c	Armature Inductance	L
Distance from CG	l	Back EMF constant	K_e
Moment of inertia	I	Torque constant	K_t
Cart traveled distance	x	Armature Inertia	J_m
Rod angle	Q	Armature Damping Coef.	b_m
Friction coefficient of the cart	c	Motor torque	T_m
Friction coefficient of the rod	b	Pulley Radius	r
Gravitational acceleration	g	Armature current	i
Reaction forces	$V,\ H$	Supply voltage	V_s

With the use of equation (7) and (8), the equations to be solved are:

$$\ddot{x} = \frac{1}{(m_c+m)}\left[-ml\left(\frac{1}{J}\left[mlg\theta - ml\ddot{x} - b\dot{\theta}\right]\right) - c\dot{x} + F\right]$$

$$\ddot{x} = -\frac{m^2l^2g\theta}{J(m_c+m)} + \frac{m^2l^2\ddot{x}}{J(m_c+m)} + \frac{mlb\dot{\theta}}{J(m_c+m)} - \frac{c\dot{x}}{(m_c+m)} + \frac{F}{(m_c+m)}$$

$$\left(1 - \frac{m^2l^2}{J(m_c+m)}\right)\ddot{x} = -\frac{m^2l^2g\theta}{J(m_c+m)} + \frac{mlb\dot{\theta}}{J(m_c+m)} - \frac{c\dot{x}}{(m_c+m)} + \frac{F}{(m_c+m)}$$

$$\ddot{x} = \frac{-m^2l^2g\theta + mlb\dot{\theta} - cJ\dot{x} + JF}{J(m_c+m) - m^2l^2} \tag{9}$$

and the corresponding of the rod angular displacement is:

$$\ddot{\theta} = \frac{1}{J}\left[mlg\theta - ml\left(\frac{1}{(m_c+m)}\left[-ml\ddot{\theta} - c\dot{x} + F\right]\right) - b\dot{\theta}\right]$$

$$\ddot{\theta} = \frac{mlg\theta}{J} + \frac{m^2l^2\ddot{\theta}}{J(m_c+m)} + \frac{mlc\dot{x}}{J(m_c+m)} - \frac{mlF}{J(m_c+m)} - \frac{b\dot{\theta}}{J}$$

$$\left(1 - \frac{m^2l^2}{J(m_c+m)}\right)\ddot{\theta} = \frac{mlg\theta}{J} + \frac{mlc\dot{x}}{J(m_c+m)} - \frac{mlF}{J(m_c+m)} - \frac{b\dot{\theta}}{J}$$

$$\ddot{\theta} = \frac{(m_c+m)mlg\theta - (m_c+m)b\dot{\theta} + mlc\dot{x} - mlF}{J(m_c+m) - m^2l^2}. \tag{10}$$

The state space design will provide the equation as follows:

$$\dot{x} = Ax + BF \tag{11}$$

$$x = \begin{bmatrix} x & \dot{x} & \theta & \dot{\theta} \end{bmatrix}^T \tag{12}$$

$$y = \begin{bmatrix} x & \theta \end{bmatrix}^T \tag{13}$$

See equation (14) below

$$B = \begin{bmatrix} 0 \\ \dfrac{J}{J(m_c+m)-m^2l^2} \\ 0 \\ \dfrac{-ml}{J(m_c+m)-m^2l^2} \end{bmatrix} \tag{15}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix}. \tag{16}$$

With some simplifying assumptions may take the field an electrical part. Based on the indicated direction of power which generated by the motor and transmitted through belt and pulley, the resultant of an electrical part is also given by

The motor equation is:

$$V - K_e\omega = L\frac{di}{dt}Ri \tag{17}$$

$$T_m - T_L = J_m\dot{\omega} + b_m\omega. \tag{18}$$

With corresponding the belt and pulley are

$$T_L = Fr \tag{19}$$

$$\omega = \frac{\dot{x}}{r}. \tag{20}$$

Substitute equations (19) and (20) into equation (18) results in

$$K_ti - rF = J_M\dot{\omega} + b_m\omega = J_M\frac{\ddot{x}}{r} + b_m\frac{\dot{x}}{r} \tag{21}$$

$$F = \frac{K_ti}{r} - b_m\frac{\dot{x}}{r^2} - J_M\frac{\ddot{x}}{r^2}.$$

From equation (9) is the governing equation for the displacement of the cart. It is common to write these equations in the standard electrical from thus be

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & \dfrac{-cJ}{J(m_c+m)-m^2l^2} & \dfrac{-m^2l^2g}{J(m_c+m)-m^2l^2} & \dfrac{mlb}{J(m_c+m)-m^2l^2} \\ 0 & 0 & 0 & 1 \\ 0 & \dfrac{mcl}{J(m_c+m)-m^2l^2} & \dfrac{(m_c+m)mlg}{J(m_c+m)-m^2l^2} & \dfrac{-(m_c+m)b}{J(m_c+m)-m^2l^2} \end{bmatrix} \tag{14}$$

used to obtain

$$\ddot{x} = \frac{-m^2l^2g\theta + mlb\dot{\theta} - cJ\dot{x} + J\left(\frac{K_i i}{r} - b_m\frac{\dot{x}}{r^2} - J_M\frac{\ddot{x}}{r^2}\right)}{J(m_c+m) - m^2l^2}$$

$$\left(J(m_c+m) - m^2l^2\right)\ddot{x} = -m^2l^2g\theta + mlb\dot{\theta} - cJ\dot{x} + J\frac{K_t i}{r} - Jb_m\frac{\dot{x}}{r^2} - JJ_M\frac{\ddot{x}}{r^2}$$

$$\left[\left(J(m_c+m) - m^2l^2\right) + \frac{JJ_M}{r^2}\right]\ddot{x} = -m^2l^2g\theta + mlb\dot{\theta} - J\left(c + \frac{b_m}{r^2}\right)\dot{x} + J\frac{K_t i}{r}.$$

$$\text{Thus} \quad J_c = \left(J(m_c+m) - m^2l^2\right) + \frac{JJ_M}{r^2} \tag{22}$$

$$\ddot{x} = \frac{-m^2l^2g\theta + mlb\dot{}\theta - J\left(c + \frac{b_m}{r^2}\right)\dot{x} + J\frac{K_t i}{r}}{J_e}.$$

Continuation of the analysis as the equation (10) is integrated to obtain:

See this equation below

The active of rod angular displacement is finally given by

$$\left[J(m_c+m) - m^2l^2\right]\ddot{\theta} = mlg\left[(m_c+m) - \frac{m^2l^2J_M}{J_er^2}\right] \times \theta - b\left[(m_c+m) - \frac{m^2l^2J_M}{J_er^2}\right] + ml\left(c + \frac{b_m}{r^2}\right)\left(1 - \frac{JJ_M}{J_er^2}\right) \times \dot{x} - ml\left(1 - \frac{JJ_M}{J_er^2}\right)\frac{K_t i}{r}.$$

When

$$M = \left[(m_c+m) - \frac{m^2l^2J_M}{J_er^2}\right],$$

$$E = \left(1 - \frac{JJ_M}{J_er^2}\right).$$

Thus

$$\ddot{\theta} = \frac{mlgM\theta - bM\dot{\theta} + ml\left(c + \frac{b_m}{r^2}\right)E\dot{x} - mlE\frac{K_t i}{r}}{J(m_c+m) - m^2l^2}. \tag{23}$$

With total inductance value L is very lower than resistance R value ($L \ll R$). The governing equation for L as a function can be neglected then the externally applied the equation for R thus is

$$V - K_e\omega \approx Ri \rightarrow i = \frac{V}{R} - \frac{K_e}{Rr}\dot{x}. \tag{24}$$

From equation (22) solution is given by

$$\ddot{x} = \frac{-m^2l^2g\theta + mlb\dot{\theta} - J\left(c + \frac{b_m}{r^2}\right)\dot{x} + J\frac{K_t\left(\frac{V}{R} - \frac{K_e}{Rr}\dot{x}\right)}{r}}{J_e}$$

$$\ddot{x} = \frac{-m^2l^2g\theta + mlb\dot{\theta} - J\left(c + \frac{b_m}{r^2}\right)\dot{x} + \frac{JK_t}{rR}V - \frac{JK_tK_e}{r^2R}\dot{x}}{J_e}$$

$$\ddot{x} = \frac{-m^2l^2g\theta + mlb\dot{\theta} - J\left(c + \frac{b_m}{r^2} + \frac{K_tK_e}{r^2R}\right)\dot{x} + \frac{JK_t}{rR}V}{J_e}. \tag{25}$$

From equation (23) solution is given by

$$\ddot{\theta} = \frac{mlgM\theta - bM\dot{\theta} + ml\left(c + \frac{b_m}{r^2}\right)E\dot{x} - mlE\frac{K_t\left(\frac{V}{R} - \frac{K_e}{Rr}\dot{x}\right)}{r}}{J(m_c+m) - m^2l^2}$$

$$\ddot{\theta} = \frac{mlgM\theta - bM\dot{\theta} + ml\left(c + \frac{b_m}{r^2}\right)E\dot{x} - \frac{mlEK_t}{rR}V + \frac{mlEK_tK_e}{r^2R}\dot{x}}{J(m_c+m) - m^2l^2}$$

$$\ddot{\theta} = \frac{mlgM\theta - bM\dot{\theta} + ml\left(c + \frac{b_m}{r^2} + \frac{K_tK_e}{r^2R}\right)E\dot{x} - \frac{mlEK_t}{rR}V}{J(m_c+m) - m^2l^2}. \tag{26}$$

$$\ddot{\theta} = \frac{(m_c+m)mlg\theta - (m_c+m)b\dot{\theta} + mlc\dot{x} - ml(\frac{K_t i}{r} - b_m\frac{\dot{x}}{r^2} - J_M\frac{\ddot{x}}{r^2})}{J(m_c+m) - m^2l^2}$$

$$\left[J(m_c+m) - m^2l^2\right]\ddot{\theta} = (m_c+m)mlg\theta - (m_c+m)b\dot{\theta} + mlc\dot{x} - ml\left(\frac{K_t i}{r} - b_m\frac{\dot{x}}{r^2} - J_M\frac{\ddot{x}}{r^2}\right)$$

$$mlJ_M\frac{\ddot{x}}{r^2} = \frac{-m^3l^3gJ_M\theta + m^2lJ_Mb\dot{\theta} - mlJJ_M\left(c + \frac{b_m}{r^2}\right)\dot{x} + mlJJ_M\frac{K_t i}{r}}{J_er^2}.$$

Let

$$b_e = c + \frac{b_m}{r^2} + \frac{K_t K_e}{r^2 R}.$$

More commonly, with

$$\ddot{x} = \frac{-m^2 l^2 g\theta + mlb\dot{\theta} - Jb_e\dot{x} + \frac{JK_t}{rR}V}{J_e} \quad (27)$$

$$\ddot{\theta} = \frac{mlgM\theta - bM\dot{\theta} + mlb_e E\dot{x} - \frac{mlEK_t}{rR}V}{J(m_c + m) - m^2 l^2}. \quad (28)$$

The state space design will provide the equation as follows:

$$\dot{x} = Ax + BV \quad (29)$$

$$x = \begin{bmatrix} x & \dot{x} & \theta & \dot{\theta} \end{bmatrix}^T \quad (30)$$

$$y = \begin{bmatrix} x & \theta \end{bmatrix}^T \quad (31)$$

See equation (32) below

$$B = \begin{bmatrix} 0 \\ \dfrac{JK_t}{J_e rR} \\ 0 \\ \dfrac{-\dfrac{mlEK_t}{rR}}{J(m_c + m) - m^2 l^2} \end{bmatrix} \quad (33)$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad (34)$$

where

$$J_e = \left(J(m_c + m) - m^2 l^2\right) + \frac{JJ_M}{r^2}$$

$$b_e = c + \frac{b_m}{r^2} + \frac{K_t K_e}{r^2 R}$$

$$M = \left[(m_c + m) - \frac{m^2 l^2 J_M}{J_e r^2}\right]$$

$$E = \left(1 - \frac{JJ_M}{J_e r^2}\right).$$

Table 2. Constant parameter.

Parameter	Symbol	Value
Rod mass	m	0.035 kg
Cart mass	mc	1.0 kg
Distance from GC of rod	l	0.135 m
Gravitational acceleration	g	$9.8\,\mathrm{m/s^2}$

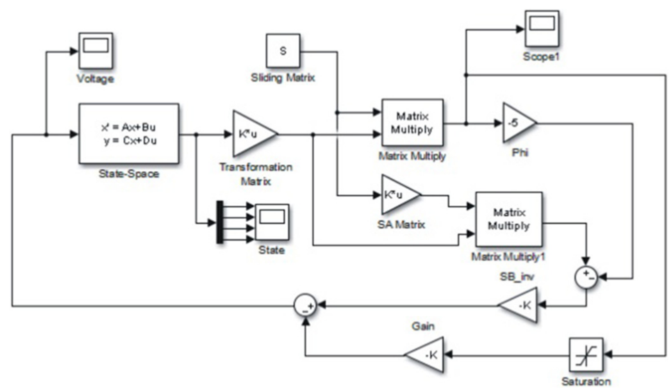


Fig. 3. The Simulink of LQR control block.

3 Results and analysis

In this research the balancing platform was balanced and controller dynamically. Balancing is accomplished either by reducing the mass or acceleration of link or by introducing forces opposite in direction of the inertia forces. Since it is often very difficult to reduce mass or acceleration of the link, the addition of forces to counteract the inertia forces is the most attractive method for reducing shaking forces.

3.1 Data analysis and Simulink

LQR control also is highly nonlinear behavior of the inverted pendulum that can design closed loop poles. It is mostly DC motor, encoder, cart, rod and electric devices or their combinations. The parameters are constant value as shown in Table 2.

The toolbox from MATLAB software can be applied in order to take the advantage of using the mathematical model of the state space control system. The Simulink model of the LQR control system can be shown in Figure 3.

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & \dfrac{-Jb_e}{J_e} & \dfrac{-m^2 l^2 g}{J_e} & \dfrac{mlb}{J_e} \\ 0 & 0 & 0 & 1 \\ 0 & \dfrac{mlb_e E}{J(m_c + m) - m^2 l^2} & \dfrac{mlgM}{J(m_c + m) - m^2 l^2} & \dfrac{-bM}{J(m_c + m) - m^2 l^2} \end{bmatrix} \quad (32)$$

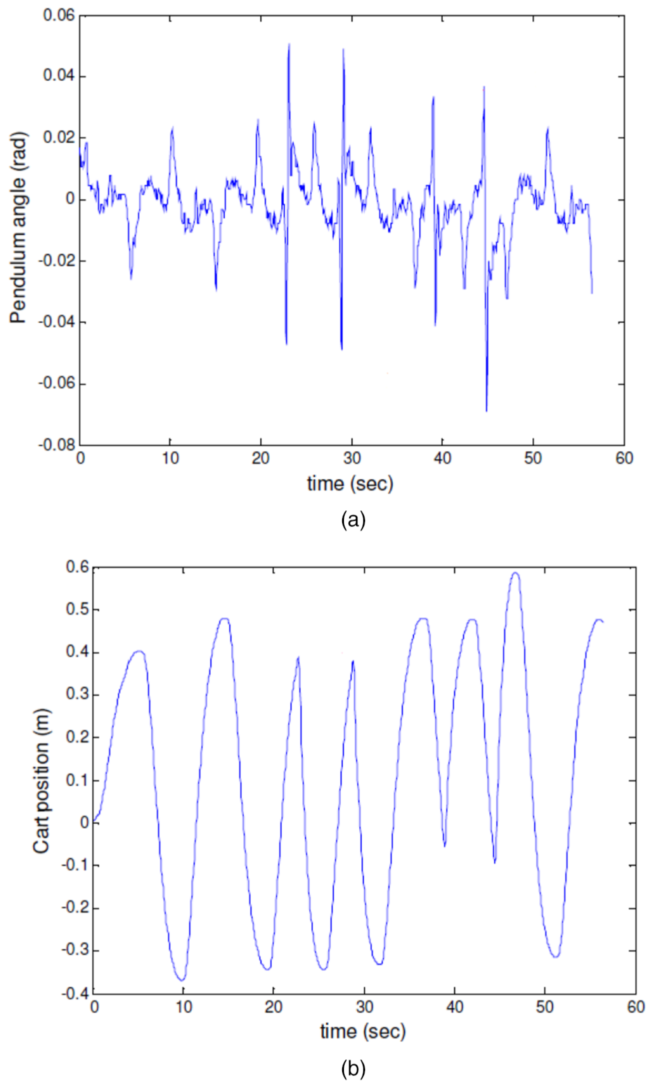


Fig. 4. The simulation result of LQR. (a) Pendulum response; (b) cart response.

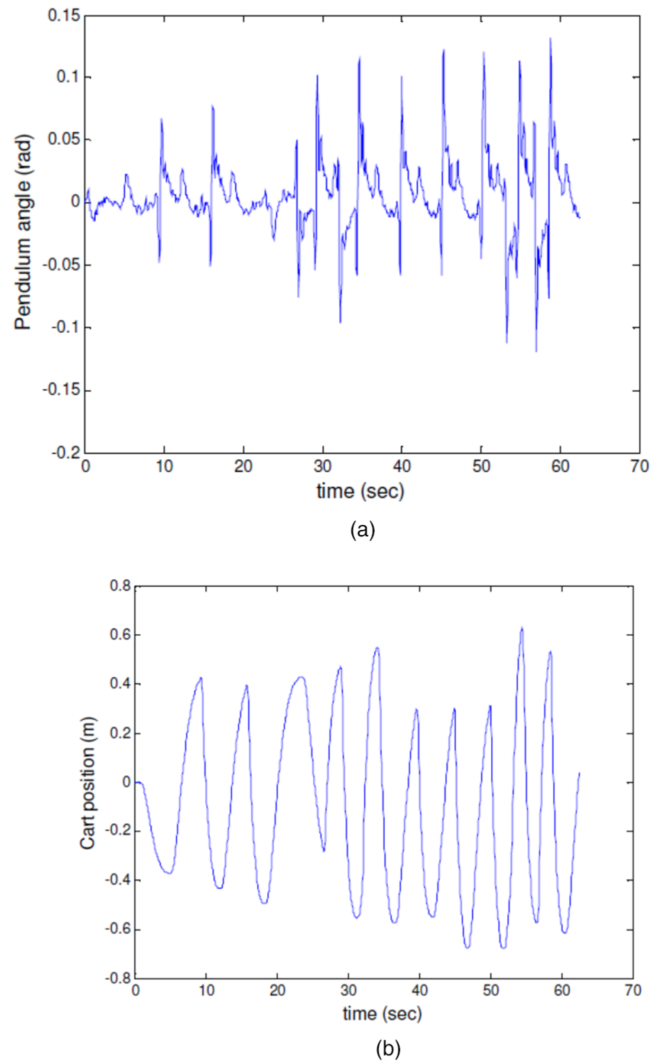


Fig. 5. The simulation result of LQR with modified the disturbance. (a) Pendulum response; (b) cart response.

3.2 LQR and results

Consider the mathematics model in equation (32) and the linear quadratic function is substitute the parameters in matrix Q and matrix R then given by

$$Q = \begin{bmatrix} 16 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 6400 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \ R = 1.$$

The weight matrix has provided the complex poles at $-13.93 \pm 12.57i$, $-0.52 \pm 0.47i$ and the optimal feedback gain matrix by pole placement method at $K = [-4.0000 \quad -11.3660 \quad -98.6862 \quad -9.5607]$ and taking the initial state condition at $x_0 = \begin{bmatrix} 0 & 0 & 10^0 & 0 \end{bmatrix}^T$. The cart and pendulum response are using of optimal feedback matrix shown in Figures 4 and 5, respectively.

The pendulum oscillated in a small range angle around -0.15 rad to 0.15 rad. However, the system has some spikes at the maximum angle around -0.07 rad to 0.05 rad. In response to balance the system, the cart moves back and forth at the range around -0.38 m to 0.58 m.

When the disturbance was altered, the system still able to balance itself. The range of angle oscillation happened from -0.125 rad to 0.125 rad. The cart travelled in the range of -0.68 m to 0.65 m. The additional disturbance caused the range of the oscillation angle increased two times larger. The cart travel distance also increased almost twice further.

The matrix can modified by using the robustness and applied the parameters in matrix Q and matrix R then given by

$$Q = \begin{bmatrix} 144 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 3600 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \ R = 1.$$

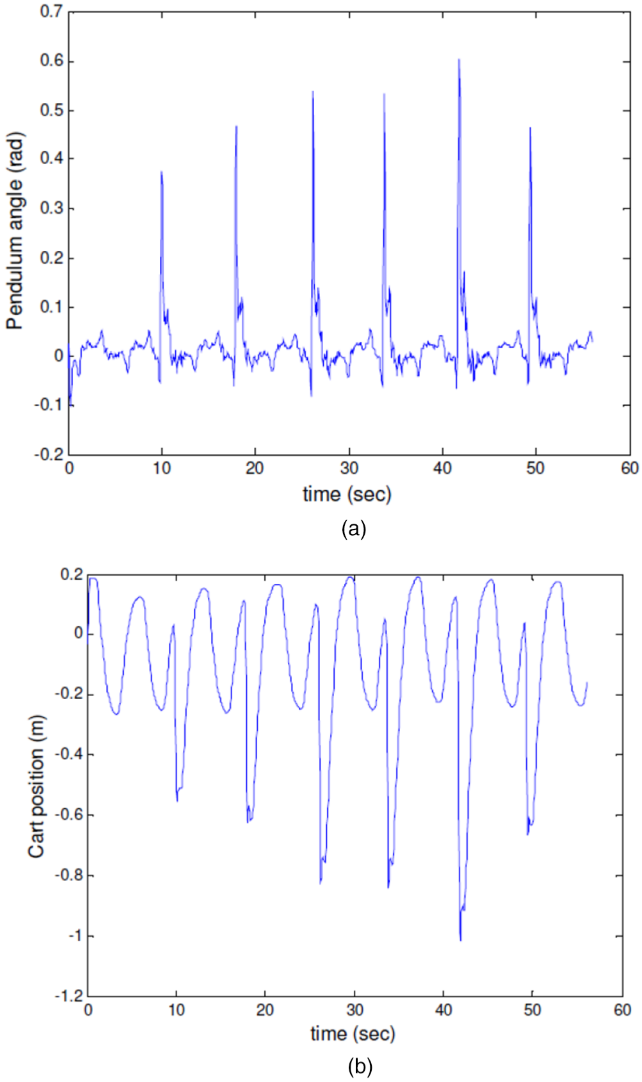


Fig. 6. The simulation result of LQR with apply the robustness. (a) Pendulum response; (b) cart response.

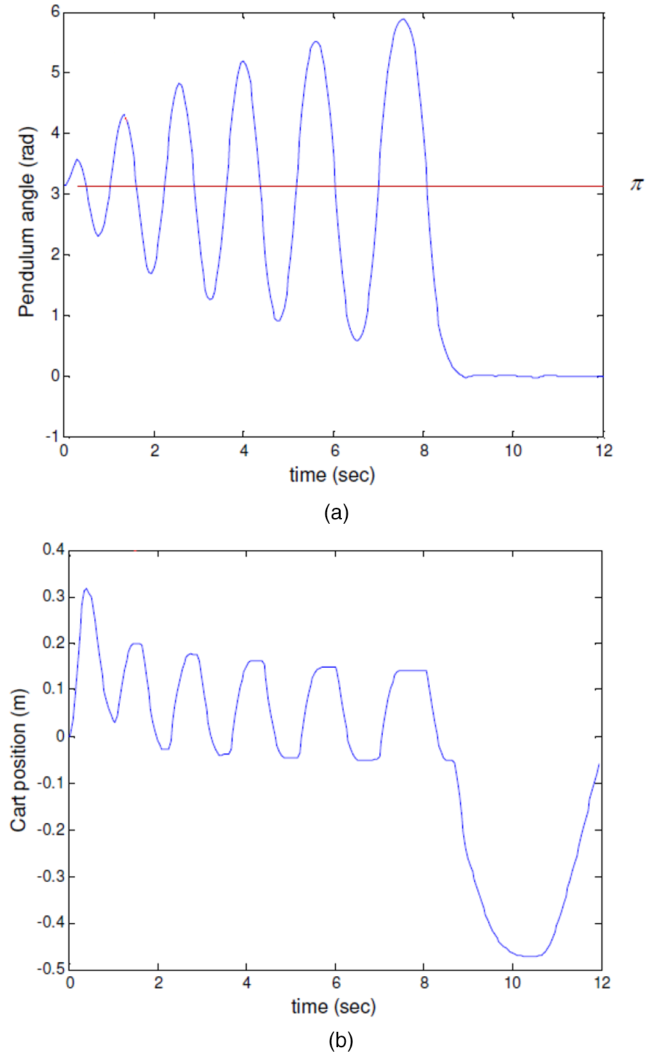


Fig. 7. The simulation result of LQR with swinging algorithm. (a) Pendulum response; (b) cart response.

The weight matrix has provided the complex poles at $-12.28 \pm 10.73i$, $-1.04 \pm 0.93i$ and the optimal feedback gain matrix at $K = [-12.0000 \quad -16.8085 \quad -89.3326 \quad -10.9879]$ and taking the initial state condition at $x_0 = \begin{bmatrix} 0 & 0 & 10^0 & 0 \end{bmatrix}^T$. The cart and pendulum response are using of robustness control matrix shown in Figure. 6.

Additional sliding mode robust control to the LQR control improved the balancing performance of the system. The robustness of the system reduced the range of pendulum oscillation. The range of the oscillation is from -0.1 rad to 0.6 rad. Even though the cart traveled a bit farther than the first experiment, but still less than the second experiment result.

The three experiments above was conducted from upright position.

Figure 7 shows the result of experiment using swinging algorithm. The pendulum starts from downward position, and then oscillate itself to reach upright position.

The system needs 9 seconds to go to upright position until stable. In order to reach the stable position, the cart traveled back and forth in the range from -0.5 m to 0.32 m.

4 Conclusion

The inverted pendulum is successfully made. The controller is using LQR. The optimal gain for the LQR to balance the inverted pendulum was found. Applying the optimal gain gives good stability. The LQR method is also used to control the cart position and the pendulum angle. The range of the pendulum oscillation without disturbance was 0.12 rad with distance range of the cart 0.96 m. When the disturbance was applied, the range of the oscillation increased to 0.25 rad and the cart distance was 1.33 m. LQR with robust algorithm has less range of oscillation, which was only 0.7 rad. However, the distance traveled by the cart while oscillated was 1.2 m. The swinging algorithm also successfully balance the system. It took 9 second for the system to bring the pendulum to the upright position and stable. The cart oscillation range was 0.82 m.

References

1. K. Udhayakumar, P. Lakshmi, Design of robust energy control for cart inverted pendulum, Int. J. Eng. Technol. **4**, 66–76 (2007)
2. B. Alan, S. Jindi, Swing-up control of inverted pendulum systems, Robotica **14**, 397–405 (1996)
3. J. Yi, N. Yubazaki, H. Kaoru, A new fuzzy for stabilization of parallel − type double inverted pendulum system, Fuzzy Sets Syst. **126**, 105–119 (2002)
4. P.C. Yon, L.C. Jeang, R.C. Sheng, PC-based sliding-mode control applied to parallel-type double inverted pendulum system, Mechatronics **9**, 553–564 (1999)
5. L. Zhongjuan, Z. Xinzheng, C. Cuohai, G. Yuguang, The modeling and simulation on sliding mode control applied in the double inverted pendulum system, IEEE World Congr. Intell. Control Autom. 1089–1091 (2012)
6. Y. Bian, J. Jiang, X. Xu, L. Zhu, Research on inverted pendulum network control technology, IEEE Third Int. Conf. Measur. Technol. Mechatr. Autom. 11–13 (2011)
7. H.Y. Luo, J. Fang, An inverted pendulum fuzzy controller design and simulation, IEEE Int. Symp. Comput. Consum. Control 557–559 (2017)
8. Y.L. Yon, L.H. Choon, M.F.W. Yen, Stabilising an inverted pendulum with PID controller, MATEC Web Conf. **152**, 1–14 (2018)
9. X. Yong, X. Jian, X. Bo, X. Hui, The inverted pendulum model with consideration of pendulum resistance and its LQR controller, IEEE Int. Conf. Electr. Mech. Eng. Inf. Technol. 3438–3441 (2011)
10. B. Ramashis, U. Naiwritadey, Stabilization of double link inverted pendulum using LQR, IEEE Int. Conf. Curr. Trends Toward Conver. Technolog. India 1–6 (2018)

Cite this article as: Dechrit Maneetham, Petrus Sutyasadi, System design for inverted pendulum using LQR control via IoT, Int. J. Simul. Multidisci. Des. Optim. **11**, 12 (2020)