Document details

IEEE Access
Volume 8, 2020, Article number 9177041, Pages 157557-157571

Assist-as-needed robotic rehabilitation strategy based on z-spline estimated functional ability (Article) (Open Access)

Mounis, S.Y.A.[a], Azlan, N.Z.[a], Sado, F.[b]

[a]Department of Mechatronics Engineering, International Islamic University Malaysia, Kuala Lumpur, 50728, Malaysia
[b]Department of Mechanical Engineering, University of Malaya, Kuala Lumpur, 50603, Malaysia

Abstract

View references (41)

Assist-as-needed (AAN) robotic - rehabilitation therapy is an active area of research which aims to promote neuroplasticity and motor coordination through active participation in functional task. A key component of this strategy is to provide robotic assistance to patients only when needed. To achieve this, accurate estimation of patients' movement/ functional ability (FA) is required to evaluate patients' need for robotic assistance and to provide the required amount of assistance, which is still a significant challenge to AAN robotic - rehabilitation therapy. This study proposes an AAN technique based on a new Functional Activity Spline Function (FASF) to estimate patients' FA and to adapt robotic assistance. The FASF is formulated using z-spline curve to estimate patients' movement ability based on the quality-of-movement and the time score of the patient in each functional task. A Linear Quadratic Gaussian Integral (LQGi) torque controller is applied with a FASF-to-torque mapping algorithm to physically provide low-level torque assistance on the elbow/shoulder joints. Fifteen patients were involved in the experimental study which consists of two tasks: (Task1) a pick-and-place task and (Task2) a table-to-mouth reaching task. The results showed that the proposed ANN control strategy has successfully estimated the patients' FA consistently with high repeatability, and able to provide the robotic assistance according to the patients' needs in the task. For different levels of impairment, the average percent-torque assistance across trials relative to the highest possible assistive torque are within the range of 5.43%-24.85% (for the mildly impaired) and 75.14%-97.14% (for the severely impaired) patents in both reaching task consistent with their FA estimation. © 2013 IEEE.

SciVal Topic Prominence

Topic: Exoskeletons | Upper Extremity | Stroke Rehabilitation

Prominence percentile: 98.572

Author keywords

a linear quadratic Gaussian (LQG) | Assist-as-needed (AAN) | functional capability | impairment | rehabilitation therapy | stroke | torque assistance and hybrid finite state automata | z-spline function

Indexed keywords

Engineering controlled terms: Conformal mapping | Patient treatment | Robotics | Torque

Related documents

A reward–punishment feedback control strategy based on energy information for wrist rehabilitation
Wang, J. , Zhang, J. , Zuo, G.
(2020) International Journal of Advanced Robotic Systems

An Assist-as-Needed Controller for Robotic Rehabilitation Therapy Based on RBF Network
Luo, L. , Peng, L. , Wang, C.
(2018) Proceedings of the International Joint Conference on Neural Networks

A Greedy Assist-as-Needed Controller for Upper Limb Rehabilitation
Luo, L. , Peng, L. , Wang, C.
(2019) IEEE Transactions on Neural Networks and Learning Systems

Engineering uncontrolled terms: Accurate estimation | Functional abilities | Functional activities | Linear quadratic Gaussian | Mapping algorithms | Motor co-ordination | Quality of movements | Robotic rehabilitation

Engineering main heading: Patient rehabilitation

Funding details

Funding sponsor	Funding number	Acronym
	FA2386-18-14105 RRD 18IOA105	

Funding text

This work was supported by the Asian Office of Aerospace Research and Development (AOARD) for the Hardware and Control Algorithm Development under Grant FA2386-18-14105 RRD 18IOA105.

ISSN: 21693536
Source Type: Journal
Original language: English
DOI: 10.1109/ACCESS.2020.3019450
Document Type: Article
Publisher: Institute of Electrical and Electronics Engineers Inc.

References (41)

View in search results format >

All Export Print E-mail Save to PDF Create bibliography

1 Al-Eithan, M.H., Amin, M., Robert, A.A.
The effect of hemiplegia/hemiparesis, diabetes mellitus, and hypertension on hospital length of stay after stroke
(2011) *Neurosciences*, 16 (3), pp. 253-256. Cited 11 times.
http://www.neurosciencesjournal.org/PDFFiles/Jul11/Effect20100714.pdf

2 Hatem, S.M., Saussez, G., della Faille, M., Prist, V., Zhang, X., Dispa, D., Bleyenheuft, Y.
Rehabilitation of motor function after stroke: A multiple systematic review focused on techniques to stimulate upper extremity recovery (Open Access)
(2016) *Frontiers in Human Neuroscience*, 10 (SEP2016), art. no. 442. Cited 197 times.
http://journal.frontiersin.org/article/10.3389/fnhum.2016.00442/full
doi: 10.3389/fnhum.2016.00442
View at Publisher

3 Pilutti, L.A., Lelli, D.A., Paulseth, J.E., Crome, M., Jiang, S., Rathbone, M.P., Hicks, A.L.
Effects of 12 weeks of supported treadmill training on functional ability and quality of life in progressive multiple sclerosis: A pilot study
(2011) *Archives of Physical Medicine and Rehabilitation*, 92 (1), pp. 31-36. Cited 70 times.
doi: 10.1016/j.apmr.2010.08.027
View at Publisher

☐ 4 Rodgers, H., Bosomworth, H., Krebs, H.I., van Wijck, F., Howel, D., Wilson, N., Aird, L., (...), Shaw, L.

Robot assisted training for the upper limb after stroke (RATULS): a multicentre randomised controlled trial (Open Access)

(2019) *The Lancet*, 394 (10192), pp. 51-62. Cited 40 times.
http://www.journals.elsevier.com/the-lancet/
doi: 10.1016/S0140-6736(19)31055-4

View at Publisher

☐ 5 Mounis, S.Y.A., Azlan, N.Z., Fatai, S.

Progress based assist-as-needed control strategy for upper-limb rehabilitation

(2017) *Proceedings - 2017 IEEE Conference on Systems, Process and Control, ICSPC 2017*, 2018-January, pp. 65-70. Cited 3 times.
ISBN: 978-153860386-4
doi: 10.1109/SPC.2017.8313023

View at Publisher

☐ 6 Nas, K., Yazmalar, L., Şah, V., Aydin, A., Öneş, K.

Rehabilitation of spinal cord injuries (Open Access)

(2015) *World Journal of Orthopaedics*, 6 (1), pp. 8-16. Cited 98 times.
http://www.wjgnet.com/2218-5836/pdf/v6/i1/8.pdf
doi: 10.5312/wjo.v6.i1.8

View at Publisher

☐ 7 Flachenecker, P.

Clinical implications of neuroplasticity - the role of rehabilitation in multiple sclerosis (Open Access)

(2015) *Frontiers in Neurology*, 6 (MAR), art. no. 036. Cited 20 times.
http://journal.frontiersin.org/article/10.3389/fneur.2015.00036/full
doi: 10.3389/fneur.2015.00036

View at Publisher

☐ 8 Pehlivan, A.U., Losey, D.P., Omalley, M.K.

Minimal Assist-as-Needed Controller for Upper Limb Robotic Rehabilitation

(2016) *IEEE Transactions on Robotics*, 32 (1), art. no. 7360218, pp. 113-124. Cited 89 times.
http://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=8860
doi: 10.1109/TRO.2015.2503726

View at Publisher

☐ 9 Houwink, A., Nijland, R.H., Geurts, A.C., Kwakkel, G.

Functional recovery of the paretic upper limb after stroke: Who regains hand capacity?

(2013) *Archives of Physical Medicine and Rehabilitation*, 94 (5), pp. 839-844. Cited 38 times.
doi: 10.1016/j.apmr.2012.11.031

View at Publisher

☐ 10 Muratori, L.M., Lamberg, E.M., Quinn, L., Duff, S.V.

Applying principles of motor learning and control to upper extremity rehabilitation

(2013) *Journal of Hand Therapy*, 26 (2), pp. 94-103. Cited 85 times.
doi: 10.1016/j.jht.2012.12.007

View at Publisher

☐ 11 Billinger, S.A., Arena, R., Bernhardt, J., Eng, J.J., Franklin, B.A., Johnson, C.M., Mackay-Lyons, M., (...), Tang, A.

Physical activity and exercise recommendations for stroke survivors: A statement for healthcare professionals from the American Heart Association/American Stroke Association (Open Access)

(2014) *Stroke*, 45 (8), pp. 2532-2553. Cited 471 times.
http://stroke.ahajournals.org/
doi: 10.1161/STR.0000000000000022

View at Publisher

☐ 12 Looi, C.Y., Duta, M., Brem, A.-K., Huber, S., Nuerk, H.-C., Cohen Kadosh, R.

Combining brain stimulation and video game to promote long-term transfer of learning and cognitive enhancement (Open Access)

(2016) *Scientific Reports*, 6, art. no. 22003. Cited 34 times.
www.nature.com/srep/index.html
doi: 10.1038/srep22003

View at Publisher

☐ 13 Hötting, K., Röder, B.

Beneficial effects of physical exercise on neuroplasticity and cognition

(2013) *Neuroscience and Biobehavioral Reviews*, 37 (9), pp. 2243-2257. Cited 332 times.
doi: 10.1016/j.neubiorev.2013.04.005

View at Publisher

☐ 14 Blank, A.A., French, J.A., Pehlivan, A.U., O'Malley, M.K.

Current Trends in Robot-Assisted Upper-Limb Stroke Rehabilitation: Promoting Patient Engagement in Therapy (Open Access)

(2014) *Current Physical Medicine and Rehabilitation Reports*, 2 (3), pp. 184-195. Cited 100 times.
springer.com/journal/40141
doi: 10.1007/s40141-014-0056-z

View at Publisher

☐ 15 Hussain, S., Jamwal, P.K., Ghayesh, M.H., Xie, S.Q.

Assist-as-needed control of an intrinsically compliant robotic gait training orthosis

(2017) *IEEE Transactions on Industrial Electronics*, 64 (2), art. no. 7490335, pp. 1675-1685. Cited 30 times.
http://ieeexplore.ieee.org/xpl/tocresult.jsp?isnumber=5410131
doi: 10.1109/TIE.2016.2580123

View at Publisher

☐ 16 Luo, L., Peng, L., Wang, C., Hou, Z.-G.

A Greedy Assist-as-Needed Controller for Upper Limb Rehabilitation

(2019) *IEEE Transactions on Neural Networks and Learning Systems*, 30 (11), art. no. 8635557, pp. 3433-3443. Cited 5 times.
http://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=5962385
doi: 10.1109/TNNLS.2019.2892157

View at Publisher

☐ 17 Rehmat, N., Zuo, J., Meng, W., Liu, Q., Xie, S.Q., Liang, H.

Upper limb rehabilitation using robotic exoskeleton systems: a systematic review

(2018) *International Journal of Intelligent Robotics and Applications*, 2 (3), pp. 283-295. Cited 17 times.
https://link.springer.com/journal/41315
doi: 10.1007/s41315-018-0064-8

View at Publisher

☐ 18 Frullo, J.M., Elinger, J., Pehlivan, A.U., Fitle, K., Nedley, K., Francisco, G.E., Sergi, F., (...), O'Malley, M.K.

Effects of assist-as-needed upper extremity robotic therapy after incomplete spinal cord injury: A parallel-group controlled trial (Open Access)

(2017) *Frontiers in Neurorobotics*, 11 (JUN), art. no. 26. Cited 14 times.
www.frontiersin.org/neurorobotics
doi: 10.3389/fnbot.2017.00026

View at Publisher

☐ 19 Peng, L., Wang, C., Luo, L., Chen, S., Hou, Z.-G., Wang, W.

A CPG-Inspired Assist-As-Needed Controller for an Upper-Limb Rehabilitation Robot

(2019) *Proceedings of the 2018 IEEE Symposium Series on Computational Intelligence, SSCI 2018*, art. no. 8628896, pp. 2200-2206.
http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=8610062
ISBN: 978-153869276-9
doi: 10.1109/SSCI.2018.8628896

View at Publisher

☐ 20 De Vito, L., Postolache, O., Rapuano, S.

Measurements and sensors for motion tracking in motor rehabilitation

(2014) *IEEE Instrumentation and Measurement Magazine*, 17 (3), art. no. 6825386, pp. 30-38. Cited 27 times.
doi: 10.1109/MIM.2014.6825386

View at Publisher

☐ 21 Krebs, H.I., Palazzolo, J.J., Dipietro, L., Ferraro, M., Krol, J., Rannekleiv, K., Volpe, B.T., (...), Hogan, N.

Rehabilitation robotics: Performance-based progressive robot-assisted therapy

(2003) *Autonomous Robots*, 15 (1), pp. 7-20. Cited 495 times.
doi: 10.1023/A:1024494031121

View at Publisher

☐ 22 Hogan, N., Krebs, H.I., Rohrer, B., Palazzolo, J.J., Dipietro, L., Fasoli, S.E., Stein, J., (...), Volpe, B.T.
Motions or muscles? Some behavioral factors underlying robotic assistance of motor recovery (Open Access)

(2006) *Journal of Rehabilitation Research and Development*, 43 (5), pp. 605-618. Cited 252 times.
http://www.rehab.research.va.gov/jour/06/43/5/pdf/hogan.pdf
doi: 10.1682/JRRD.2005.06.0103

View at Publisher

☐ 23 Papaleo, E., Zollo, L., Spedaliere, L., Guglielmelli, E.
Patient-tailored adaptive robotic system for upper-limb rehabilitation

(2013) *Proceedings - IEEE International Conference on Robotics and Automation*, art. no. 6631120, pp. 3860-3865. Cited 26 times.
ISBN: 978-146735641-1
doi: 10.1109/ICRA.2013.6631120

View at Publisher

☐ 24 Vergaro, E., Casadio, M., Squeri, V., Giannoni, P., Morasso, P., Sanguineti, V.
Self-adaptive robot training of stroke survivors for continuous tracking movements (Open Access)

(2010) *Journal of NeuroEngineering and Rehabilitation*, 7 (1), art. no. 13. Cited 72 times.
doi: 10.1186/1743-0003-7-13

View at Publisher

☐ 25 Perez-Ibarra, J.C., Siqueira, A.A.G., Krebs, H.I.
Assist-As-needed ankle rehabilitation based on adaptive impedance control

(2015) *IEEE International Conference on Rehabilitation Robotics*, 2015-September, art. no. 7281287, pp. 723-728. Cited 19 times.
http://ieeexplore.ieee.org/xpl/conferences.jsp
ISBN: 978-147991807-2
doi: 10.1109/ICORR.2015.7281287

View at Publisher

☐ 26 Wolbrecht, E.T., Chan, V., Reinkensmeyer, D.J., Bobrow, J.E.
Optimizing compliant, model-based robotic assistance to promote neurorehabilitation

(2008) *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 16 (3), pp. 286-297. Cited 322 times.
doi: 10.1109/TNSRE.2008.918389

View at Publisher

☐ 27 Bower, C., Taheri, H., Wolbrecht, E.
Adaptive control with state-dependent modeling of patient impairment for robotic movement therapy

(2013) *IEEE International Conference on Rehabilitation Robotics*, art. no. 6650460. Cited 15 times.
ISBN: 978-146736024-1
doi: 10.1109/ICORR.2013.6650460

View at Publisher

28 Huang, R., Cheng, H., Chen, Q., Tran, H.-T., Lin, X.

Interactive learning for sensitivity factors of a human-powered augmentation lower exoskeleton

(2015) *IEEE International Conference on Intelligent Robots and Systems*, 2015-December, art. no. 7354293, pp. 6409-6415. Cited 26 times.
ISBN: 978-147999994-1
doi: 10.1109/IROS.2015.7354293

View at Publisher

29 Obayashi, C., Tamei, T., Shibata, T.

Assist-as-needed robotic trainer based on reinforcement learning and its application to dart-throwing

(2014) *Neural Networks*, 53, pp. 52-60. Cited 17 times.
doi: 10.1016/j.neunet.2014.01.012

View at Publisher

30 Liu, Q., Liu, A., Meng, W., Ai, Q., Xie, S.Q.
Hierarchical compliance control of a soft ankle rehabilitation robot actuated by pneumatic muscles
(2017) *Frontiers Neurorobotics*, 11, p. 64. Cited 12 times.
Dec.

31 Sado, F., Yap, H.J., Ghazilla, R.A.R., Ahmad, N.

Exoskeleton robot control for synchronous walking assistance in repetitive manual handling works based on dual unscented kalman filter (Open Access)

(2018) *PLoS ONE*, 13 (7), art. no. e0200193. Cited 6 times.
http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0200193&type=printable
doi: 10.1371/journal.pone.0200193

View at Publisher

32 Nelles, O.
(2013) *Nonlinear System Identification: From Classical Approaches to Neural Networks and Fuzzy Models*. Cited 2427 times.
Springer

33 Whitall, J., Savin Jr., D.N., Harris-Love, M., Waller, S.M.

Psychometric Properties of a Modified Wolf Motor Function Test for People With Mild and Moderate Upper-Extremity Hemiparesis

(2006) *Archives of Physical Medicine and Rehabilitation*, 87 (5), pp. 656-660. Cited 69 times.
doi: 10.1016/j.apmr.2006.02.004

View at Publisher

34 Zhao, J.-L., Chen, P.-M., Li, W.-F., Bian, R.-H., Ding, M.-H., Li, H., Lin, Q., (...), Huang, D.-F.

Translation and initial validation of the Chinese version of the action research arm test in people with stroke (Open Access)

(2019) *BioMed Research International*, 2019, art. no. 5416560. Cited 3 times.
http://www.hindawi.com/journals/biomed/
doi: 10.1155/2019/5416560

View at Publisher

35 Hodics, T.M., Nakatsuka, K., Upreti, B., Alex, A., Smith, P.S., Pezzullo, J.C.

Wolf motor function test for characterizing moderate to severe hemiparesis in stroke patients

(2012) *Archives of Physical Medicine and Rehabilitation*, 93 (11), pp. 1963-1967. Cited 50 times.
doi: 10.1016/j.apmr.2012.05.002

View at Publisher

36 van der Lee, J.H., Roorda, L.D., Beckerman, H., Lankhorst, G.J., Bouter, L.M.

Improving the action research arm test: A unidimensional hierarchical scale

(2002) *Clinical Rehabilitation*, 16 (6), pp. 646-653. Cited 61 times.
doi: 10.1191/0269215502cr534oa

View at Publisher

37 Mounis, S.Y.A., Azlan, N.Z., Sado, F.

Assist-as-needed control strategy for upper-limb rehabilitation based on subject's functional ability (Open Access)

(2019) *Measurement and Control (United Kingdom)*, 52 (9-10), pp. 1354-1361. Cited 2 times.
http://mac.sagepub.com/content/by/year
doi: 10.1177/0020294019866844

View at Publisher

38 Platz, T., Pinkowski, C., van Wijck, F., Kim, I.-H., di Bella, P., Johnson, G.

Reliability and validity of arm function assessment with standardized guidelines for the Fugl-Meyer Test, Action Research Arm Test and Box and Block Test: A multicentre study

(2005) *Clinical Rehabilitation*, 19 (4), pp. 404-411. Cited 442 times.
doi: 10.1191/0269215505cr832oa

View at Publisher

39 Niyetkaliyev, A.S., Hussain, S., Ghayesh, M.H., Alici, G.

Review on Design and Control Aspects of Robotic Shoulder Rehabilitation Orthoses

(2017) *IEEE Transactions on Human-Machine Systems*, 47 (6), art. no. 7932920, pp. 1134-1145. Cited 18 times.
http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=6221037
doi: 10.1109/THMS.2017.2700634

View at Publisher

40 Lyle, R.C.

A performance test for assessment of upper limb function in physical rehabilitation treatment and research

(1981) *International Journal of Rehabilitation Research*, 4 (4), pp. 483-492. Cited 765 times.
doi: 10.1097/00004356-198112000-00001

View at Publisher

41 Yozbatiran, N., Der-Yeghiaian, L., Cramer, S.C.

A standardized approach to performing the action research arm test

(2008) *Neurorehabilitation and Neural Repair*, 22 (1), pp. 78-90. Cited 280 times.
doi: 10.1177/1545968307305353

View at Publisher

Azlan, N.Z.; Department of Mechatronics Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia; email:sinnira@iium.edu.my