Yanpeng ZHENG, Guijie ZHANG, Xiaoyu JIANG, Zhaolin JIANG, Sung-Kwun OH, 2026. A neural network algorithm for superstructure quadrilateral dynamic resistor networks on hammock surfaces with application to artificial intelligence. *ENGINEERING Information Technology & Electronic Engineering,* 27(6):260055. https://doi.org/10.1631/ENG.ITEE.2026.0055

A neural network algorithm for superstructure quadrilateral dynamic resistor networks on hammock surfaces with application to artificial intelligence

Key words: Zeroing neural network; Resistor network; Laplacian system; Equivalent resistance; Potential; Path planning

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Motivation

1. Resistor networks are widely used to model complex physical and engineering systems, providing an effective framework for analyzing current flow and network behavior.
2. Many practical resistor networks are inherently time-varying, making traditional static analysis methods insufficient for real-world applications.
3. The computational burden increases rapidly with network size, which limits the efficiency of conventional numerical solvers.

4. Fast and accurate solutions are desirable for intelligent applications, such as robotic navigation and path planning.

Main idea

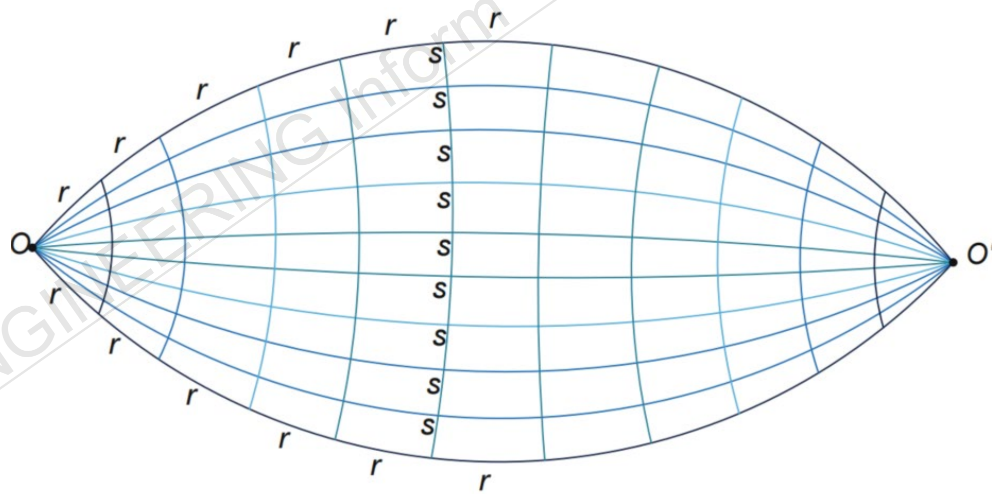
1. Model the dynamic hammock resistor network as a time-varying Laplacian system and formulate the corresponding potential computation problem.
2. Develop a fast zeroing neural network for hammock resistor networks (FZNNHRN) to track the theoretical solution in real time.
3. Exploit the special matrix structure using FFT-, DST-, and DCT-based techniques to accelerate computation.

4. Apply the computed potential field to robot path planning, demonstrating the effectiveness of the proposed framework.

Method

1. A dynamic hammock resistor network is first constructed to model time-varying electrical systems. By applying Kirchhoff's laws, the network is transformed into a time-varying Laplacian equation, where the node potentials can be obtained by solving

$$\boldsymbol{L}_{mn}^{\text{hammock}}(t)\boldsymbol{V}(t) = \boldsymbol{\mathcal{I}}$$



Structure of the hammock resistor network with $m = n = 10$, where vertical and horizontal resistances are denoted by *r* and *s*, respectively. The hammock resistor network is rotated by 90° clockwise for clarity and layout.

Method (Cont'd)

2. To compute the node potentials of the dynamic resistor network in real time, an FZNNHRN is developed. The solver converts the potential computation problem into a dynamic error-tracking process and guarantees convergence to the theoretical solution.

$$\frac{\mathrm{d}\boldsymbol{E}(t)}{\mathrm{d}t} = -\boldsymbol{\kappa}(t)\boldsymbol{\mathcal{F}}(\boldsymbol{E}(t))$$

$$\boldsymbol{E}(t) = \boldsymbol{L}_{mn}^{\mathrm{hammock}}(t)\boldsymbol{V}(t) - \boldsymbol{\mathcal{I}}$$

$$\boldsymbol{\kappa}(t) \; = \; \gamma\left(\left(\boldsymbol{L}_{mn}^{\mathrm{hammock}}(t)\right)^{\mathrm{T}}\boldsymbol{L}_{mn}^{\mathrm{hammock}}(t) + \lambda\boldsymbol{E}_{mn}\right)^{k}$$

Method (Cont'd)

3. To further improve computational efficiency, the structural properties of the Laplacian matrix are exploited. FFT-, DST-I-, and DCT-III-based techniques are incorporated to accelerate matrix operations, significantly reducing the computational complexity for large-scale resistor networks.

$\mathbb{S}_m^{\mathrm{I}}$ is the type-I discrete sine transform (DST-I), defined as

$$\mathbb{S}_m^{\mathrm{I}} = \left(\sqrt{\frac{2}{m+1}} \sin \frac{jk\pi}{m+1}\right)_{k,j=1}^{m}, \tag{21}$$

and $\mathbb{C}_n^{\mathrm{III}}$ is the type-III discrete cosine transform (DCT-III), defined as

$$\mathbb{C}_n^{\mathrm{III}} = \left(\sqrt{\frac{2}{n}} d_k \cos \frac{(k-1)(2j-1)\pi}{2n}\right)_{k,j=1}^{n}, \tag{22}$$

with $d_k = \min\left\{1, \frac{\sqrt{2}}{2} - 1 + k\right\}$.

Computational complexity: $O(N^3) \rightarrow O(N \log_2 N)$

Major results

Comparison of computational efficiency among different models

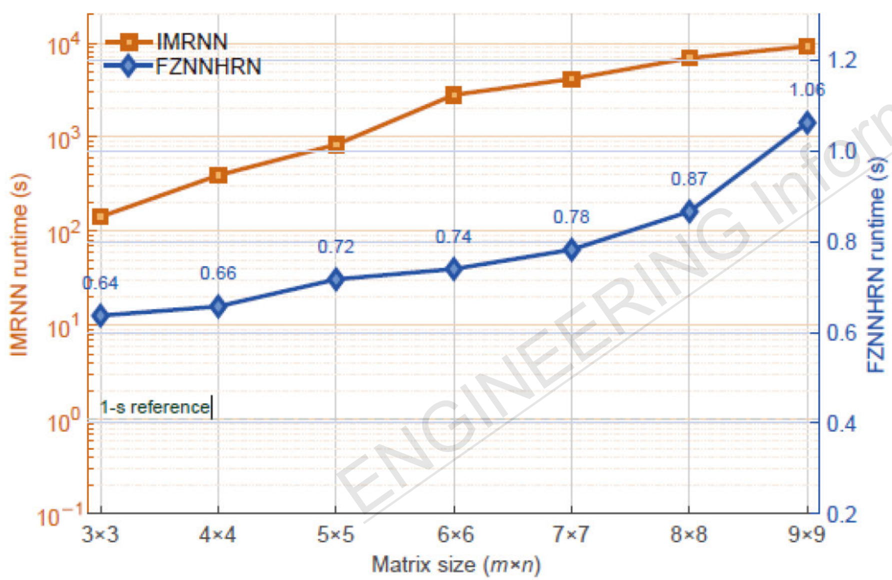


Fig. 3 CPU runtime comparison between IMRNN and FZNNHRN

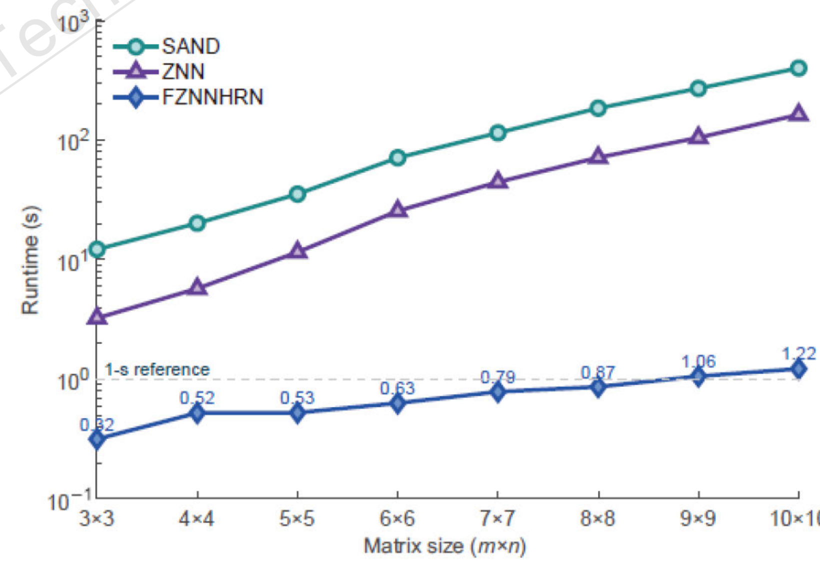
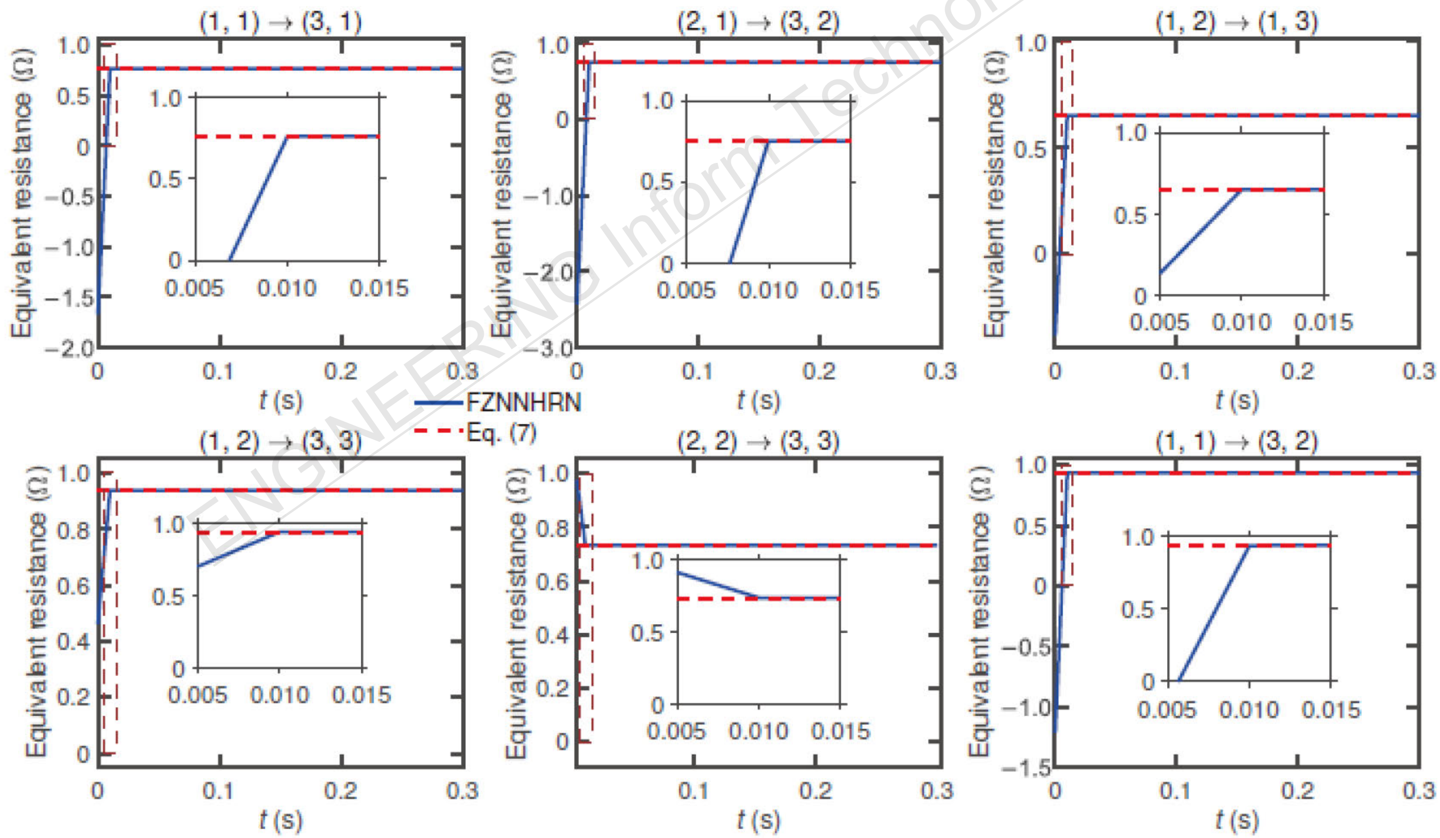


Fig. 4 CPU runtime comparison between FZNNHRN and other methods

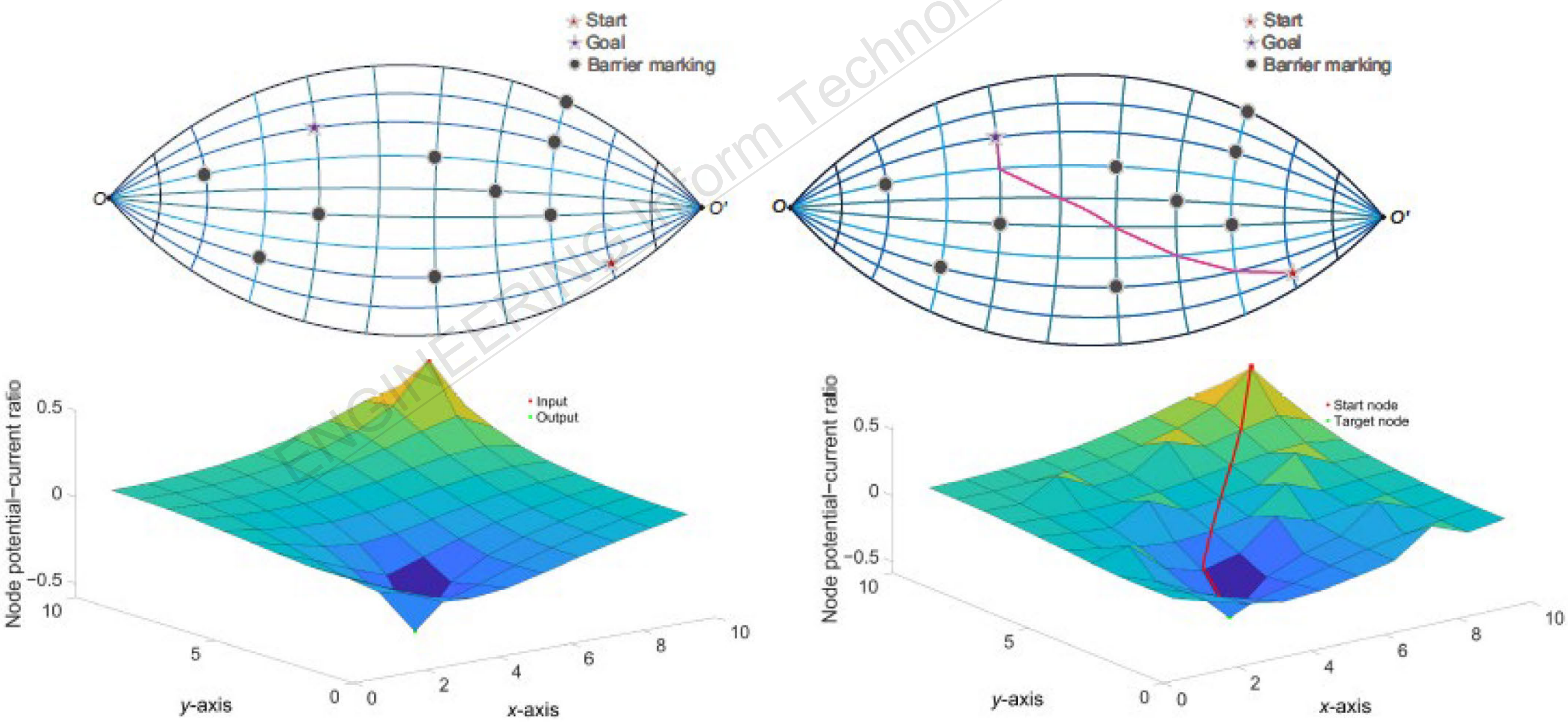
Major results (Cont'd)

The equivalent resistances computed by FZNNHRN closely match the analytical solutions, demonstrating the accuracy of the proposed method.



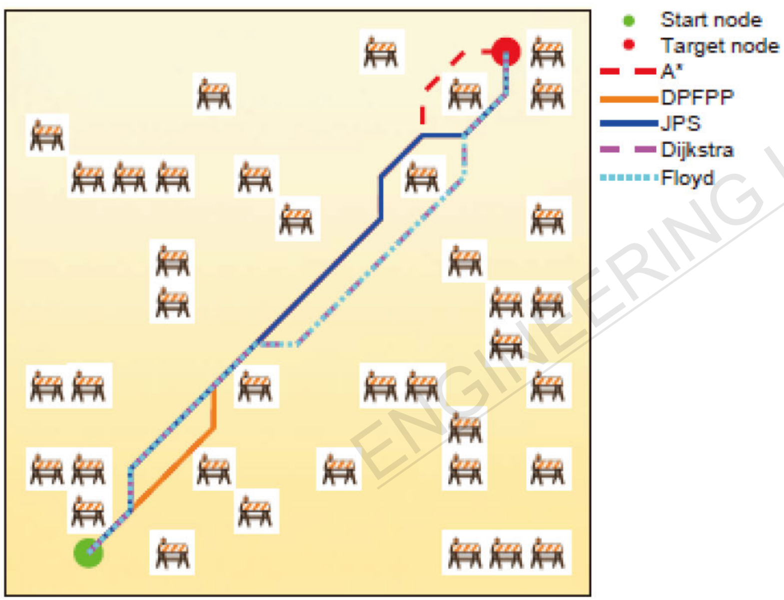
Application

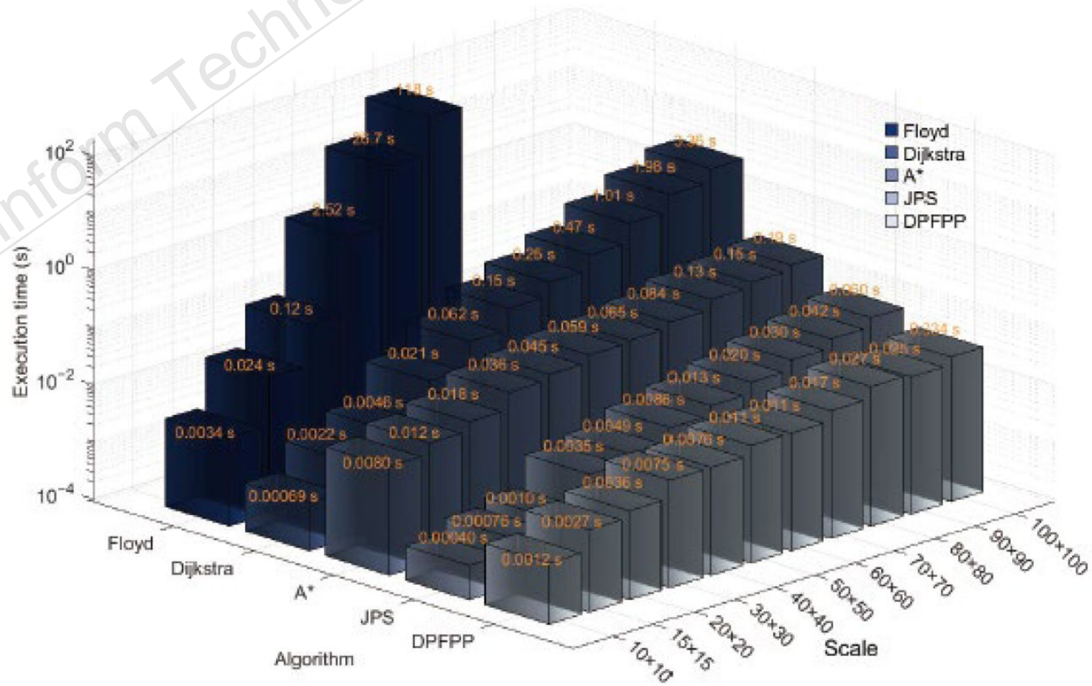
The computed node potentials can be naturally transformed into a potential field, providing an effective foundation for robot path planning.



Application(Cont'd)

Compared with existing path-planning methods, the proposed framework significantly reduces the computational time required to generate feasible paths.





Conclusions

1. A dynamic hammock resistor network model is established.

2. An efficient FZNNHRN solver is developed for real-time potential computation.

3. Fast transform techniques significantly improve computational efficiency.

4. The proposed framework is successfully applied to robot path planning.

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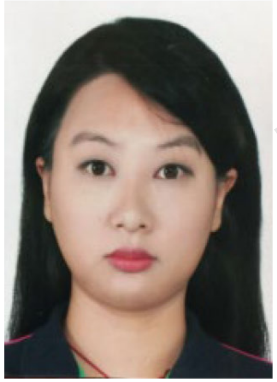

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