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Dynamic Potential Field-based Assisted-as-Needed Control Strategy for Robotic Post-Stroke Rehabilitation

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INTRODUCTION

Stroke remains a leading cause of adult disability worldwide, resulting in significant motor impairments and reduced quality of life [1]. Robot-Assisted rehabilitation has emerged as an effective therapeutic intervention, offering consistent, quantifiable, and intensive treatment. The integration of gamification in robot-assisted rehabilitation can lead to more interactive and engaging sessions. Assist-as-Needed (AAN) control strategy is essential in robot-assisted rehabilitation, as it aims to provide minimal assistance for task completion, thus promoting active participation and motor learning [2]. However, designing an effective AAN particularly for complex tasks remains a challenge. In our previous work [3], we developed a tuneable rehabilitation task based on a hot-wire game where patients navigate through random obstacle pairs to reach the endpoint. And an obstacle-free path is pre-computed using our modified A* algorithm with Bezier curve smoothing for each game. This work proposes a dynamic potential field–based AAN control strategy that keeps patients close to the pre-computed path while providing progressive assistance for task completion..

MATERIALS AND METHODS

The rehabilitation task is designed in a 2D planner workspace where the patients is required to navigate from a start point to an end point while avoiding obstacles. To enable an AAN control strategy, we define a dynamic, tuneable scalar potential field that assists the patient in completing the task. The overall potential field is defined as: $\varphi(x, y, l_i) = \varphi_r(x, y) + \lambda \cdot \varphi_{prog}(x, y, l_i)$. where $\varphi_r(x, y)$ is the radial component, which guides the patient within a safe region around the pre-computed path and $\varphi_{prog}(x, y, l_i)$ is progression component, which dynamically promotes forward movement toward task completion and λ is a weighting factor. Before each trial, a safe radius $r(x, y)$ is assigned to every point on the path, determined by obstacles proximity and tuneable minimum value based on patient history and level of desired assistance, forming a no-intervention zone where minimal assistance is provided. For each point on the workspace mesh grid, the radial potential is computed using a sigmoid function: $\phi_r(x, y) = \frac{1}{1+\exp\left(-k\left(d_{xy}(x,y) - r(x,y)\right)\right)}$ Where $d_{xy}(x, y)$ is the Euclidean distance from (x, y) to the nearest point on the path, $r(x, y)$ is the safe radius at that path index, and k is a tuneable steepness parameter of the sigmoid. We assign a arbitrary Z value to every path point based on (l_i) remaining path length to the end point. The rate of change of Z values will dynamically update based on user performance and desired task completion speed. The change only applies from the current path index to the endpoint, ensuring a monotonically decreasing trend toward the goal. The progression component $\varphi_{prog}(x, y, l_i)$ for workspace point is determined by Z values of closest path index. Finally, the resulting guidance force is obtained as the negative gradient of the potential field: $\vec{F}(x, y) = -\nabla\phi(x, y)$

RESULTS AND DISCUSSION

Figure 1 illustrates an example potential field for a pre-computed path with constant safe radius of $r(x, y) = 0.5cm$ and sharpness factor $K = 15$. In the initial case(left), the progression rate is zero, and the filed is shaped only by sigmoid(radial) component, guiding the patient towards the path. When progression is activated at a rate of 0.2 (right), the Z values along the remaining path (with the black line indicating the affected region) update dynamically, deepening the potential field toward the endpoint and adding forward guidance toward task completion.

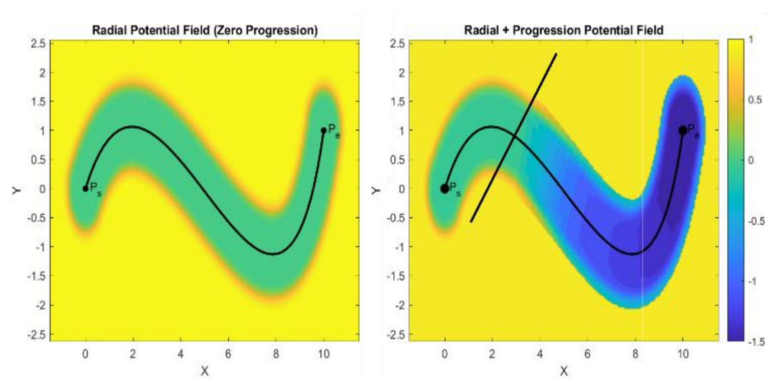

Fig 1 *Example potential fields: radial-only case (Z rate = 0) and progression-active case (Z rate = 0.2).*

CONCLUSIONS

We have developed a dynamic potential field for AAN control for robot-assisted rehabilitation that is tuneable both offline(safe radius, sigmoid sharpness, initial progression rate, desired task speed) and online (progression rate), enabling personalized assistance based on patient history and real-time performance. This individualized strategy aims to provide adaptive support that promotes active participation and successful task completion.

REFERENCES

[1] Krueger H et al. Stroke 46: 2226-2231, 2015.
[2] Atashzar SF et al. Mechatronics 57: 1-19, 2019.
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