Gait Dynamics And Optimization Using The Robot-Assisted Lower Extremity Training Platform

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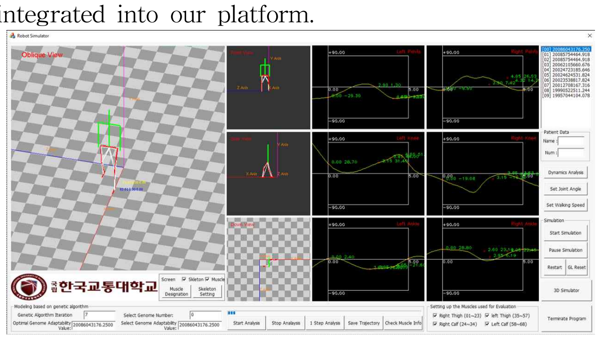
Abstract - Improving the efficiency of a medical rehabilitation regimen is critical for a patient's quicker recovery. By combining walking motion synthesis, joint kinematics, musculoskeletal model reconstruction, and dynamic analysis, our platform generates optimal gait patterns suited to each user's rehabilitation needs.

1. Introduction

The modeling of the developed robot system was inspired by the bio-mechanics of the human body, with the simulation platform being built around the robot's interaction with the external environment. Our platform allows medical practitioners and users to analyze and alter their gait pattern in real-time to build a personalized rehabilitation regimen based on each joint's range of motion, walking speed, and musculoskeletal features. Orthogonal projections of the robot skeleton for joint trajectory visualization, customizable muscle and musculoskeletal parameters, a simulation and rehabilitation task development toolbox, and data logging are some of the notable features integrated into our platform.



<Fig 1> The developed lower extremity gait pattern simulation and analysis software.

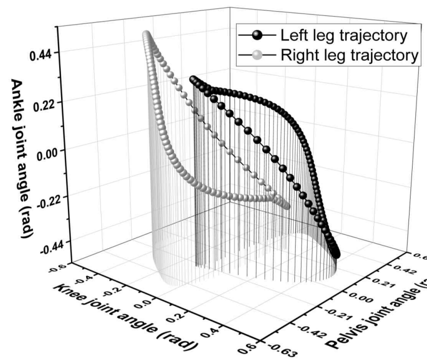
2. Gait Trajectory Optimization

2.1 Evaluation based on Genetic Algorithm

Establishing a natural gait pattern is vital for the user; this can be done by using a Genetic Algorithm (GA) that maximizes force generation in each muscle group targeted for rehabilitation. The muscle force calculation model is also a fitness evaluation function computed using eq. (1) that takes into account the maximum muscle flexion force (F_m^{Max}), physiologic cross-sectional area (PCSA) values, normalized muscle activity values (M_a), muscle movement velocity (V_m), and muscle length (δ_m). We utilize this method to assess how well the motion generated by simulation fits the motion described by the user's musculoskeletal and joint range of motion characteristics [1][2].

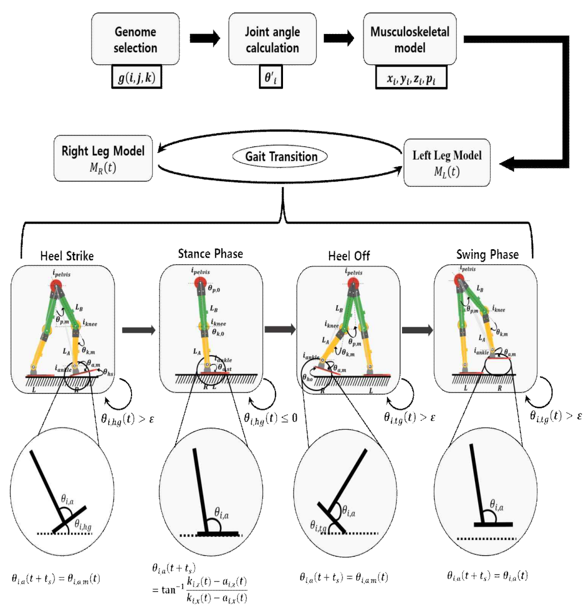
$$E = F_m^{Max}\left(U_{(\delta_m)}, F_{(\delta_m, V_m)}\right) M_a \quad (1)$$

The GA's initial population comprises of joint position and trajectory information recorded in each gene that describes the transition state angles of the knee, pelvis and ankle joints [3]. Following evaluation, genetic cross-over and mutation operations are carried out until termination conditions are reached, at which time the corresponding gene with the best fitness values is adopted as the new joint trajectory upon simulation using the ground contact model shown in Fig.3.



<Fig 2> Optimized lower extremity joint trajectory visualization at a walking speed of 0.20 m/s.

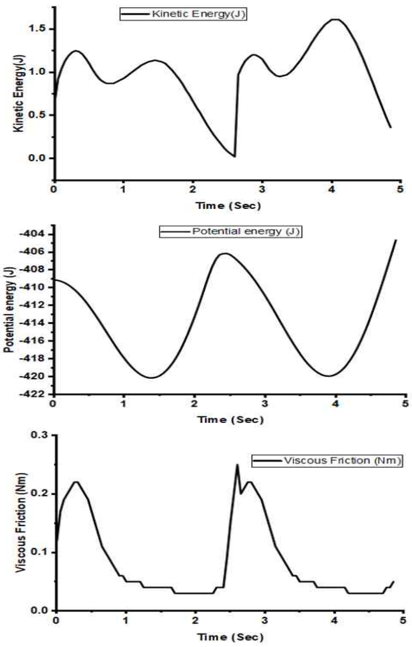
Since wearable rehabilitation robots lack fixed ground contact points, our model is built on kinematic transition state analysis, which evaluates the contact angles between the toe, heel, and ankle in relation to the point of contact with the ground during footfall. This enhances the gait heuristic algorithm, which can be used on diverse terrain.



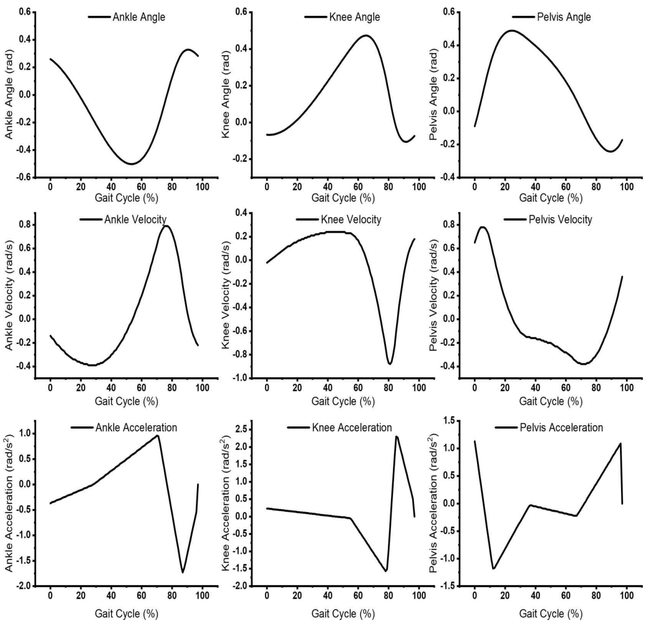
<Fig 3> Adaptation to environment through simulation.

2.2 Dynamic analysis

The optimized gait trajectory data is subjected to dynamic analysis. Kinetic energy, potential energy and viscous friction parameters for left and right legs during walking are obtained by incorporating Lagrangian mechanics into the dynamic computing engine of the modeling software. We can further acquire the trajectory, velocity, and acceleration of the ankle, knee, and pelvis joints. The resulting information is utilized to calculate joint torques, joint forces, and ground reaction forces. The simulation results are presented in Fig. 4 and Fig. 5 respectively.



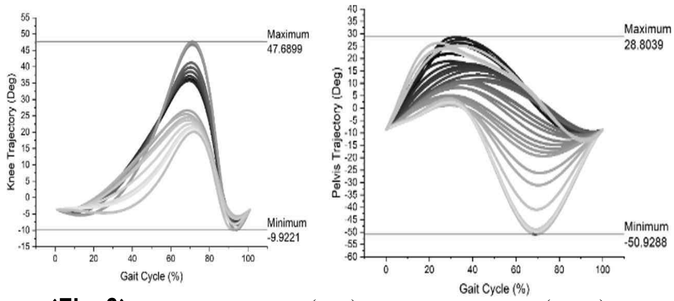
<Fig 4> The Kinetic energy (K.E), Potential Energy (P.E) and Viscous friction simulation results for left and right legs respectively.



<Fig 5> The simulation results for lower extremity joint trajectory, velocity and acceleration..

2.3 Walking stability variable

The simulation-based study of 20 gait patterns is graphically represented below. The maximum flexion and extension for knee and pelvis joints depicting the safe and normal walking limits are shown in Fig.4. However, using the developed personalized robotic operation platform, the user can opt to adjust the range of motion based on the assistance level sought.



<Fig 6> The knee joint (left) and pelvis joint (right) bounds for safe and normal walking pattern.

3. Conclusion

By providing recognized feedback to physicians and users, the developed platform enhances human-robot interaction and improves training criteria to achieve a natural walking pattern based on the reflection of rehabilitation goals such as expanding joint range of motion, strengthening muscles, and improving gait balance.

<Fig 7> The developed treadmill based stationary type exoskeleton robot for lower extremity rehabilitation.

Acknowledgement

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[References]

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