Adaptive Regulation for Hybrid Zero Dynamics based Exoskeletons with Model Uncertainty

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I. BACKGROUND

Hybrid zero dynamics (HZD) offers a mathematical framework that allows working with the full order dynamics of the robotic model to achieve stable bipedal locomotion. The resulting gait is periodic, however, deviations from the resulting orbit might lead to unstable motion. A common practice to maintain stability is to use heuristic regulators to achieve foot placement locations that follow human-like strategies. In this work, instead of producing a heuristic-only regulator, we use an adaptive neural network regulator that generates joint-level modifications and stabilizes the walking gait under model uncertainty, commonly found in exoskeleton systems.

II. METHODS

The HZD gait optimization produces desired joint trajectories parameterized by Bézier polynomials to be tracked by an appropriate control law $(y^a(q) \rightarrow y^d(\tau))$ [1]. The regulation changes directly the desired joint references by applying an offset $\bar{y}^d(\tau) = y^d(\tau) + \delta q$. In [2], we computed $\delta q = J^{+}(y^d_{CoM} - y^a_{CoM})$ to correct for the lateral center of mass deviations, an analysis of the jacobian revealed that the most active joints during regulation are the frontal and sagittal hips. To provide a more flexible approach we developed a neural-network based adaptive regulator, which provides two components: $\delta \mathbf{q}^d_x$, offset to desired swing sagittal hip and $\delta \mathbf{q}^d_y$, offset to the swing frontal hip, as shown below:

$$\delta q^d_x = K_p(v^d_x - v^a_x[k]) + K_d(v^a_x[k] - v^a_x[k-1]) + \Psi_x, \quad (1)$$

$$\delta q^d_y = K_p(v^d_y - v^a_y[k]) + K_d(v^a_y[k] - v^a_y[k-1]) + \Psi_y, \quad (2)$$

where Ψ_x, Ψ_y are one hidden layer neural-networks reducing the error in velocity, v^d_x, v^d_y are the desired forward and side velocities. and v^a_x, v^a_y are the actual forward and side velocities [3]. The functional link neural network policy comprises one hidden layer with fixed random-initialized input weights, and delta rule learned output weights. During the test, the training is performed in real-time, taking about 40 seconds to produce convergence to the desired velocity.

III. RESULTS & DISCUSSION

The generation of gaits was solved with the HZD optimization package FROST in MATLAB. The COM regulator and adaptive regulator successfully maintained stability and tracking forward velocity in the gait with 5 cm/s of nominal speed. In addition, the adaptive regulator has efficiently tracked the forward velocity of gaits of 10 and 15 cm/s as seen in Fig. 1 under significant changes (e.g., increases in mass by $\pm 30kg$). The adaptive regulator also provides extra robustness against impulsive external forces of up to 400 N. The model-independent adaptive regulator is ideal for lower-limb exoskeletons because they must sustain different users that introduce unknown dynamics.

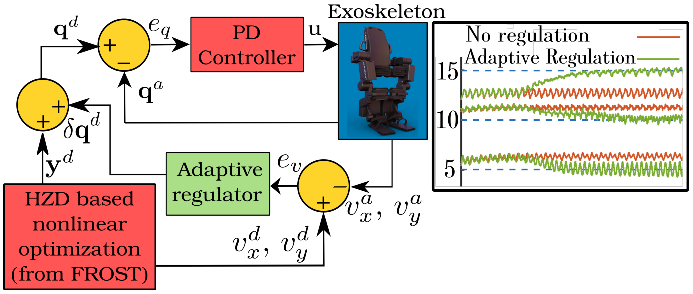

Fig. 1. Neural adaptive regulation applied to the hybrid zero dynamics framework, the blue dashed line represents the reference speed for three different speeds of 5, 10 and 15 cm/s under model uncertainty.

IV. CONCLUSION

It is observed that the adaptive regulator produces a more robust and flexible approach with respect to the previous COM regulator. Furthermore, it can stabilize different gait speeds in the presence of model uncertainties and withstand external disturbances [3] with a computationally low-cost structure that is ideal for implementation on the exoskeleton hardware.

REFERENCES

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