Using machine learning to predict foot placement during walking

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I. Introduction

Predicting future foot placements during walking can have several applications from designing gait exoskeleton controllers to predicting falls and mobility impairments. Biomechanical studies reported that foot placement is correlated with and thus can be predicted from the centre of mass (COM) and foot kinematic during the preceding step [1-2]. Model-based predictive models which have traditionally been used to predict gait trajectory (including foot placements) have limited capacity due to their simplicity and low to average accuracy. Machine learning methods are thus a viable approach for foot placement prediction. However, no study has yet tried to develop predictive models of gait foot placement using machine learning techniques. The goal of this study was to develop a machine learning model to predict next anterior-posterior (AP) and mediolateral (ML) foot placement based on the kinematics of the current foot placement. Specifically, we aimed at investigating the effect of i) walking speed, and ii) adding swing foot kinematics at the current step together with the COM kinematics on the performance of the model.

II. Methods

We used a publicly available dataset [3] of healthy young individuals walking on a treadmill at three slow (0.8 m/s), normal (1.2 m/s), and fast (1.6 m/s) speeds. A random forest regressor with 100 estimators (trees) was used. To test our first aim, the model was trained and tested using data of each speed, separately. To test our second aim, two sets of inputs were used for the model, i) COM position, velocity, and acceleration in the AP and ML directions at the mid-stance and the participants' height (7 inputs in total), and ii) adding swing foot kinematics at mid-stance in the AP and ML directions to the previous inputs (13 inputs in total). The output of the model (labels) was the AP and ML positions of the next foot placement at heel strike. The data were split into training (80%) and test (20%) sets. A 5-fold cross validation was used to train the model. The mean absolute error (MAE) and coefficient of determination (R^2) between the predicted and actual foot placements were used to test the model's performance.

III. Results and Discussion

The results are presented in Table 1. When adding both COM and foot kinematics as inputs to the model, both slow and fast walking reduced model accuracy in predicting AP and ML foot placement, a result reported by previous studies on the correlation between pelvis kinematics and foot placement [1]. When including the COM as the only input, slow walking slightly improved model accuracy (MAE=1.90) compared to normal walking (MAE=2.00). This observation could explain previous reports that indicated slow walking decreased ML step variability and thus increased gait ML stability [4]. Adding swing foot kinematics as the input reduced the MAE and increased R^2 in all speeds indicating that prediction of future foot placement could be improved by including both the COM and foot kinematics at the preceding mid-stance.

TABLE I. Results of the model for the test dataset

		Walking speed					
		Slow		**Normal**		**Fast**	
Input type	**Measure**	**AP**	**ML**	**AP**	**ML**	**AP**	**ML**
COM	**MAE (cm)**	2.10	1.90	1.70	2.00	1.90	2.70
	R^2	0.95	0.91	0.97	0.84	0.96	0.72
COM and foot	**MAE (cm)**	2.10	1.60	1.70	1.30	1.80	1.60
	R^2	0.96	0.93	0.97	0.96	0.96	0.93

IV. Conclusion

Machine learning techniques can be used to accurately predict next foot placement using the COM and foot kinematics in the preceding step. The implications are estimating foot placement optimality detection in affected populations and designing feed-forward controllers for gait exoskeletons.

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References

[1] K. Stimpson, L. Heitkamp, J. Horne, and J. Dean. "Effects of walking speed on the step-by-step control of step width". *J. Biomech*, vol. 68, pp. 78–83, 2018.

[2] S. Collins, A. Kuo. "Two Independent Contributions to Step Variability during Over-Ground Human Walking." *PLoS ONE*, vol. 8, pp. e73597, 2013.

[3] J. Moore, S. Hnat, A. van den Bogert . "An elaborate data set on human gait and the effect of mechanical perturbations." *PeerJ*, pp. 3e918, 2015.

[4] B. Maki. "Gait Changes in Older Adults: Predictors of Falls or Indicators of Fear?". *J. Am. Geriatr. Soc.*, vol. 45, pp. 313-320, 1997.