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Dynamic Modeling and Classification-Based Fall Risk Assessment in Elderly Populations

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1. Introduction

Population aging is a growing global concern, with the number of individuals aged over 60 expected to exceed 22% by 2050 (WHO 2021). The increase in life expectancy, coupled with the prevalence of chronic and neurodegenerative diseases (Parkinson) presents significant societal challenges to ensure elderly well-being, early prevention of fall risks and disease development. In addition to loss of independence and the higher rate of injury and death, falls leads to anxiety and a sedentary lifestyle tendency due to fear of falling. To address this, early detection and diagnosis of people at high risk allows better fall prevention among the elderly with or without Parkinson's disease. Several clinical tests are available for postural balance analysis including questionnaires (FES, Fall experience in the past 12 months), functional tests (BEST), and stabilography evaluation. The most common quantitative measure of body balance is the displacement of the center of pressure (COP) (Nnodim et al. 2015, Quijoux et al. 2021). With technological advancements, integrating artificial intelligence techniques can offer new perspectives to make

diagnosis easier and more automated for postural balance analysis. Hence, the use of artificial intelligence algorithms combined with COP signals has become increasingly common for predicting fall risk in older adults. This is achieved through machine learning (ML) based on descriptive features extracted from COP signals in both time and frequency domains (Giovannini et al., 2018; Liao et al., 2021). More recently, Tawaki et al. 2022 examined the classification accuracy of fall risk using COP parameters derived from a Mass Spring Damper Model of balance, based on fall-experience assessments. However, the model's capability to take into consideration pathology and more specific clinical diagnosis (like FES, BEST) remains to be evaluated. This study aims to assess the effectiveness of physical features extracted from a dynamic model of human balance: (i) to distinguish healthy individuals from those with Parkinson's disease, and (ii) to further differentiate fallers within these groups.

2. Method

2.1 Databases and fall classes definition

We used, in this study, two datasets for the evaluation of human balance: (1) the Santos (2017) dataset with 76 healthy elderly population (HE) and (2) the Boari (2021) dataset with 32 individuals with mild to moderate Parkinson's disease (PD). First, subjects were asked to perform a quiet standing test for 30s-60s on a force platform with different testing conditions: rigid /foam surfaces and open and close eyes. COP measurements were collected. Second, based on the Fear of Falling Efficacy Scale (FES) questionnaire, subjects with higher fear of falling score were affected to fall-risk group. "Fallers" group is then composed of 16 HE and 10 PD.

2.2. Dynamic model

A mass-spring-damper (MSD) model was used to examine postural control via COP displacements (Tawaki et al. 2022). This model includes a mass (m), a spring with stiffness (k), and a damper with viscosity (d), representing the movement in the sustentation's plane (x, y). For each experimental trial, the damping coefficient ξ , the natural frequency ω and stochastic perturbation η were estimated from the mediolateral and anteroposterior balance directions using the least squares method.

2.3 Machine Learning process

After min-max scaling to prevent the dominance of features with large amplitudes, data were divided into 80% for training, 10% for cross validation, and 10% for test. Data were randomly assigned to each subset to ensure that the splits were representative of the fall conditions. K-Nearest Neighbors (KNN) model was

used because its effectiveness to capture local patterns and variations in the data. evaluated using the accuracy and the F1-score which represents respectively, the proportion of correct predictions relative to the total number of instances and the balance between precision and recall.

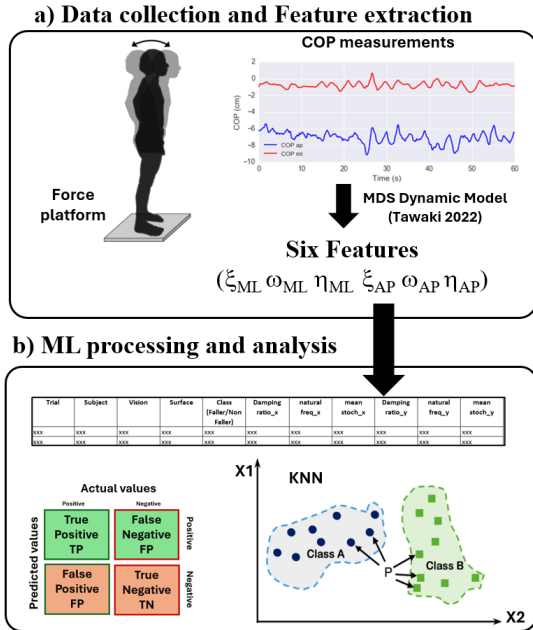


Figure 1. Data collection and Processing Flowchart

3. Results and discussion

The first objective is to assess the algorithm's accuracy in differentiating between Healthy Elderly (HE) and Parkinson's Elderly (PE) using features extracted from the MDS model. In fact, KNN classifier demonstrates high accuracy in distinguishing between HE and PE groups, with an accuracy rate of 99.5 (± 0.05) %. This aligns with literature findings indicating that viscosity and stochastic coefficients are affected by aging and disease.

Performances of the KNN algorithm to distinguish between "fallers" and "non fallers" within both HE and PE groups are illustrated in table 1. Overall, the model is more accurate at identifying fallers within the HE population, with a high accuracy and F1-score (95% and 93% respectively). Better performances were observed for HE under Open Eyes and Foam Surface conditions, with 97% F1-score. This suggests that upright posture may be used for faller detection in clinical routines for balance evaluation. Alternatively, Eyes Closed under Firm Surface conditions can be proposed for safety reasons, as the KNN achieves a 93% F1-score.

Table 1. KNN Classifier Performances to distinguish "fallers" and "non fallers" individuals within healthy (HE) and Parkinson's disease (PE) elderly groups

Conditions	population	Accuracy	F1-Score	
			faller	non faller
All conditions	HE	0.95	0.93	0.96
	PE	0.68	0.55	0.76
Eyes Closed	HE	0.96	0.93	0.94
Firm Surface	PE	0.60	0.57	0.63
Eyes Closed	HE	0.95	0.86	0.91
Foam Surface	PE	0.53	0	0.49
Eyes Opened	HE	0.96	0.92	0.95
Firm Surface	PE	0.69	0.64	0.73
Eyes Opened	HE	0.98	0.97	1
Foam Surface	PE	0.56	0.31	0.72

However, the KNN algorithm faces challenges in accurately identifying fallers among the PE population with lower accuracy and F1-Score (68% and 55% respectively) observed for all conditions. Furthermore, the model fails to predict "fallers" during balance tasks on foam surfaces (0 and 0.31 values of F1-score respectively) and achieves moderate accuracy on rigid surfaces, with F1-scores of 0.64 and 0.5. This indicates that fear of falling may be more pronounced in the Parkinson's population when performing balance under unstable conditions, such as with closed eyes or on foam surfaces. These findings suggest that further refinement of the model or inclusion of additional features may be necessary to improve its performance in identifying fallers, particularly within the Parkinson's disease population.

4. Conclusions

Evaluating the balance ability of individuals for the prevention of falls is a social and medical need. Using physical parameters representing balance (damping coefficient, natural frequency) derived from COP measurements, the KNN classifier effectively differentiated between healthy (HE) and pathological populations (PE). However, the fall classification model is more accurate at identifying fallers from non-fallers in HE than in PE populations and struggles to predict fallers during balance tasks on foam and rigid surfaces. In sum, the use of the MDS model can provide physical insights into the causes of decline in postural control ability due to natural aging or disease stages and can help in designing optimal clinical tests that reduce physical and psychological harm. Improving fall detection performance in Parkinson's population may require model refinement or additional

features or exploration of complex models like inverted pendulum balance.

Conflict of interest

The authors declare that they have no conflicts of interest to report regarding the present study

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